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ICWMC 2018 Editors

Jaime Lloret Mauri, Polytechnic University of Valencia, Spain

ICWMC 2018

Forward

The Fourteenth International Conference on Wireless and Mobile Communications (ICWMC 2018), held between June 24, 2018 and June 28, 2018 in Venice, Italy, continued a series of events dedicated to advanced wireless technologies, wireless networking, and wireless applications.

ICWMC 2018 addressed wireless related topics concerning integration of latest technological advances to realize mobile and ubiquitous service environments for advanced applications and services in wireless networks. Mobility and wireless, special services and lessons learnt from particular deployment complemented the traditional wireless topics.

The conference had the following tracks:

- Mobility Trends
- Performance Evaluation, Simulation and Modeling of wireless networks and systems
- Mobile Systems

We take here the opportunity to warmly thank all the members of the ICWMC 2018 technical program committee, as well as all the reviewers. The creation of such a high quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated their time and effort to contribute to ICWMC 2018. We truly believe that, thanks to all these efforts, the final conference program consisted of top quality contributions.

We also gratefully thank the members of the ICWMC 2018 organizing committee for their help in handling the logistics and for their work that made this professional meeting a success.

We hope that ICWMC 2018 was a successful international forum for the exchange of ideas and results between academia and industry and to promote further progress in the field of advanced wireless technologies, wireless networking, and wireless applications. We also hope that Venice, Italy provided a pleasant environment during the conference and everyone saved some time to enjoy the unique charm of the city.

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Mobile Technology and Conservation Areas: A Case Study

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***Abstract*—This article addresses the importance of mobile technologies as a method to assist in the process of denouncing environmental crimes. With the purpose of helping the citizens of Tocantins (Northern Brazilian state), by giving them means to denounce illegal practices, this work helps with environmental preservation. The research presented is relevant in helping with environmental protection.**

Keywords-mobile technologies; complaint; environment crimes; preservation; environment.

I. INTRODUCTION

This research intends to yield useful information for someone and to enable that someone to apply it. In order to receive this type of useful information on the way it is used, several factors have to be taken into consideration, for instance the relevance of the information and what the impacts and transformations will involve. Confronting with this, it is observed that one of the major concerns at present and for future generations is the environment and its indiscriminate use.

According to the law of environmental crimes, the normative act materialized in Federal Brazilian Law nº. 9.605/98, environmental crime is all use of natural and mineral resources that violates the limits established by law [1].

Hence, the protection and conservation of renewable and nonrenewable natural resources require actions beyond existing legislative instruments, leaving the theoretical field and being more effective. Thereupon, technology can help in the environmental protection of a dynamic and agile way in favor of the environment.

Historically, in Brazil, the process of denouncing crimes against the environment is accomplished in person where the citizen goes to the responsible environmental organ to complain, or uses the telephone service to communicate the illicit practices harmful to the environment. Those models of complaint are restricted by population, i.e., not always can whoever makes the denunciations reach the competent authorities, or they are attended by phone calls due to the great number of unanswered phone calls. It should also be observed that the attendance at public agencies operates at restricted hours, and is unavailable on weekends or holidays. Therefore, there are no people to receive those complaints, and forward them to the surveillance group for immediate environmental protection activities [2].

In this regard, the project presented in this article is the use of mobile technologies, allowing every citizen to carry out criminal denunciations against the environment, interacting directly from the source of the infraction, at any time, through mobile devices connected by Internet.

To this extent, the project also intends to solve the problem of the limitations in the process of carrying out criminal denunciations against the environment, allowing greater speed and efficiency, in an effort to provide assistance to the responsible agencies for environmental surveillance.

For that reason a mobile application was created for the Android operating system. Called Preserve.TO, it which simplifies and innovates the process of denouncing crimes against the environment in the State of Tocantins, and can be adapted to anywhere in the world.

This article is structurally organized in the following manner: in section I - introduction, which presents the problem, justification, objectives, and organization of the text. In section II - related research, which are studies already accomplished in this area. In section III - proposition, which describes what was done. In section IV - methodology, explains what and how it was done. In section V - results, which comprehends the data obtained in the research in relation to the mobile application. In section VI - conclusion and future research.

II. RELATED RESEARCH

This section will deal with research related to the goal of this article. Besides that, it mentions information considered relevant, emphasizing the similarities and differences among them.

A research topic that has great similarity to the work developed in this article shows the use of mobile technology to help combat sexual violence, collecting evidence through the MediCapt application that allows investigative professionals to collect evidence relating to the crimes of a sexual nature and to send this information to a database, and which can be investigated afterwards by the lawful authorities or used as criminal evidence in court. MediCapt has the same purpose as Preserve.TO, because it is a digital means for collecting information that can be forwarded to the competent authorities to evaluate those digital data, and if it involves a punishable criminal offense, to apply the appropriate penalties to those who have infringed the laws [3].

The course conclusion paper presented at the undergraduate course in Computer Science at the University of Southern Santa Catarina (*Universidade do Sul de Santa Catarina*, in Portuguese), in 2015, entitled "Collaborative System for Identifying and Denouncing Environmental Crimes" ("*Sistema Colaborativo para Identificação e Denúncia de Crimes Ambientais*", in Portuguese) presents a project for a system of environmental crimes to enable the collaboration and active participation of society in environmental preservation, focusing on crimes against fauna, flora and pollution. The application developed was mainly destined for mobile devices using the camera features and Global Positioning System (GPS) along with a Web version [4].

The article presented at the "VIII Brazilian Congress of Environmental Management" ("*VIII Congresso Brasileiro de Gestão Ambiental*", in Portuguese) held in Campo Grande / Mato Grosso do Sul from November 27th to 30th, 2017, entitled as "'Brigade On Line' Application: The Use of Technology to Contribute to the Combat of Forest Fires" ("*Aplicativo 'Brigada On Line': O Uso da Tecnologia para Aporte ao Combate de Incêndios Florestais*", in Portuguese) reports a very similar application to the one presented in this article. "Brigada On Line" application, as well as the Preserve.TO, are applications that have been developed for smartphones and tablets, aimed at helping preserve the environment through denunciation to the competent agencies. Both tools use geographic coordinates resources, obtained by GPS, image records, and text fields to detail the location [5].

Those projects, just as the one presented in this article, have used tools that furnish mobility information, both from a collection and availability point of view. In other words, the mobile networks along with the connectivity of devices through 3G, 4G and Wireless networks allow these solutions to go where the information is generated and bring them to the population, reaching as many people as possible. In this regard, ubiquitous access to information is offered from the moment that it is generated until the moment it is provided.

III. Proposition

Our proposition with this research is to provide to citizens of Tocantins with mechanisms through mobile technology that allow them to denounce, in a voluntary way, actions of degradation against the environment in the State of Tocantins, whether the environmental crime is in urban or rural areas. To this extent, the relationship between society and public administration becomes closer. These denunciations might be directly linked to the environmental protection agencies, such as the Brazilian Institute of the Environment and Renewable Natural Resources (*Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis* - Ibama / in Portuguese) and the Nature Institute of Tocantins (*Instituto Natureza do Tocantins* - Naturatins / in Portuguese), so those agencies can investigate and if penalties apply, the lawbreaker will be punished for attacking the environment, being held liable according to current legislation.

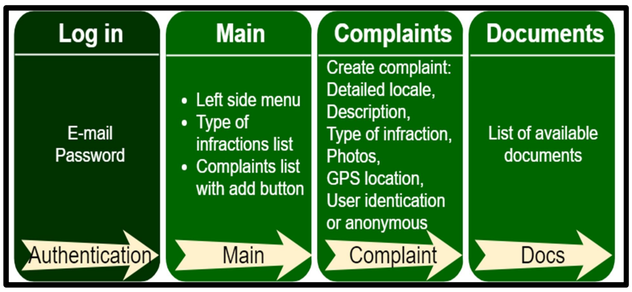

Figure 1. Solution flowchart.

As illustrated in Figure 1, a project is presented to enable assistance to society and environmental defense agencies. This is accomplished through the development of a mobile application in which the user can accomplish the denunciations, informing the detailed location, the nature of infraction, classified into types of infractions, photos of the occurrence, the geographical coordinates through GPS and identification of the person making the denunciation through user authentication, because the access in the application is initially performed by email and password, or the denunciation may be provided anonymously. After registering the denunciation via device, it can be sent to the application server, allowing the availability to the competent agencies. These accusations can be deleted from the mobile device at any time by the authenticated user.

As well as recording and sending denunciations, the project contains a document module, which is can offer links to current environmental legislation and several related materials.

IV. Methodology

This section will present the methodological steps and technologies used in the project proposed in this article.

A centralized Web structure was created containing information on the types of environmental infractions, receipt of denunciations, authentication and authorization of users. A mobile application was also developed for the Android operating system, for application of this data, generation and sending of denunciations by the project users. Communication between Web and mobile applications is done through Web services using JavaScript Object Notation (JSON).

The first stage of the development was the survey of the requirements, being made with interviews with Mr. Erivaldo Martins, an employee at Naturatins, the public agency responsible for environmental monitoring in the State. Initially, the following requirements and functionalities of the system were drawn up: list and consultation of the nature of the infraction, city of origin of the infraction, report of the occurrence, detail, photos and geographical coordinates of the place of incident, and complainant. The denunciation can be anonymous.

After the requirements were surveyed, the implementation part of the project was started. To that end, Microsoft Visual Studio Community integrated development environment was used with the C# (C Sharp) programming language and Microsoft SQL Server Express database for web application development, and the integrated Android Studio development environment with the Java programming language, extensible markup language (XML), and Realm database for mobile application development.

After the project began to take shape, part of it, the Web server, to receive and manage denunciations, which was hosted on a virtual server on Google Cloud Platform, so that the team could access the application and perform testing, synchronizing data, making registrations, testing queries, making suggestions, tracking and improving the development process.

With the application working in its beta version, mathematical formulas presented in (1) and (2) were applied to obtain statistical data for validation of the research. Faced with such a situation, the sample, the standard deviation and the estimated error were determined. The analyzes were performed using the formula presented in (1).

$$s = (\sigma\, x\, \frac{1.96}{E})^{2} \qquad (1)$$

Being:

- s: sample.
- σ: standard deviation.
- 1.96: 95% confidence.
- E: estimated error.

In a pre-sample of application ratings, with options from 1 to 5, 1 being poorly satisfied and 5 being very satisfied, the following values were found:

- Pre-sample: {4, 2, 5, 3, 5}.

With the standard deviation on this pre-sample of 1.303840481, the result shown in (2) was obtained.

$$s = (\frac{(1.303840841\, x\, 1.96)}{(1.303840481\, x\, 0.15)})^{2} \qquad (2)$$

The result of s = 170.7377778 was obtained.

With the application of this mathematical formula shown in (2), we have the sample population size for validation of the research, from a universe of 170.7377 people.

A form was prepared this sample population to answer and evaluate the project. This form is digitally found through Google Forms, where the user of the application could answer seven questions from the researchers, to gather pertinent information for the use of the application, in order to obtain a valid result, which is in fact to know if the application will help to fight environmental crimes in the state of Tocantins.

After a usable version of the Preserve.TO project was ready, its use was put into practice by making the mobile application available on Google Play Store through the Android Package (APK) application.

One of the researchers is a Naturatins employee. He was one of the main persons for presenting the application to this institution, where all the coworkers were very enthusiastic and used the application in its evaluative test phase.

The project was also displayed to academics from the Federal Institute of Education, Science and Technology of Tocantins (*Instituto Federal de Educação, Ciência e Tecnologia do Tocantins* – IFTO, in Portuguese), Palmas campus, where the researchers explained the proposition of Preserve.TO, giving instructions about how to obtain it through their smartphones or tablets and also guiding the students that after using this application, the research form was answered, providing information to the researchers as to whether the project would be useful in the combat against environmental crimes.

V. RESULTS

The public-opinion poll was drawn up with seven questions, with each question containing five alternatives, on a scale of one to five. Rating one corresponds to poor, rating two corresponds to fair, rating three corresponds to good, rating four corresponds to very good and rating five corresponds to excellent.

In this public-opinion poll we tried to extract from people who used the project what they thought of the proposition and whether, in fact, this could help in the preservation of the environment.

The questions used, in the following order, were: Do you believe that it is really possible to help to preserve the environment through the use of this application?; In the environment in which you live, is the use of this application relevant for preserving the environment?; Evaluate the proposition of the application, in sense of helping in the fight against environmental crimes, in relation of the utility; Has the application it easy to made a denunciation?; Do you believe that the application is able to aid in the agility of environmental crime surveillance, preventing even greater disaster?; Does the use of new technologies, such as the one developed in this application, contribute to the preservation of natural resources?; Which rating would you assign to recommend this application?.

A total of 172 (one hundred and seventy-two) answers to this questionnaire were obtained. For the first question, according to Figure 2, 61.6% of the respondents answered “Certainly”, 32.6% answered “Yes”, 4.7% answered “Maybe”, while 1.2% answered “Not much”, with the estimated sampling error of 0.04886% for each response. A variance of 0.4106% and a standard deviation of 0.6408% were found.

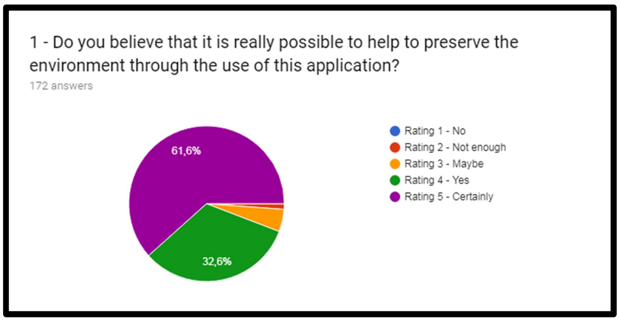

Figure 2. Answers to the first question on the form.

For the second question, we tried to extract from the application users the relevance of the technology. The percentage acquired is presented in Figure 3. The sample fractions obtained were rating 1, which represents “No”, one of the research participants attributed this rating, meaning that the majority of all who answered the public-opinion poll believe that the use of the application is relevant to for supporting preservation of the environment. Therefore, it follows that 99% of people believe that the application can promote actions in defense of the environment. However, within this universe, 0.6% answered “No”, 2.3% answered “Not much”, 7.6% answered “Maybe”, 34.3% answered “Yes” and 55.2% answered “Certainly”.

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Given this second question, which has a variance of 0.6028 and a standard deviation of 0.7764, it can be inferred that the population believes that the use of the Preserve.TO application is important for aiding environmental preservation.

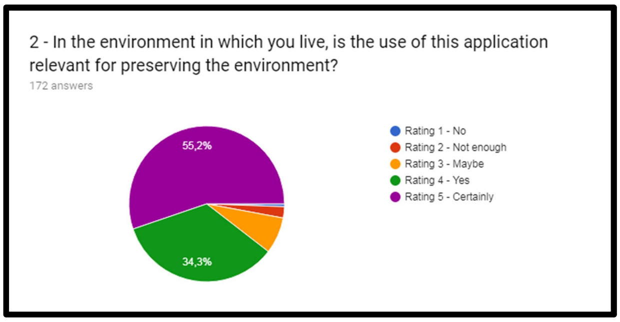

Figure 3. Answers to the second question on the form.

On the third question, rating 1 was not assigned, which has the description “Poor”, so it can be seen that 100% of interviewees do not think that the application project is a bad idea. However, within this sample scenario, 1.2% answered “Fair”, 13.4% answered “Good”, 25% answered “Very Good” and 60.5% answered “Excellent”. With a variance of 0.5844 and standard deviation of 0.7645, most evaluations have been concentrated on very good and excellent, assigning the application as an important utility tool, Figure 4.

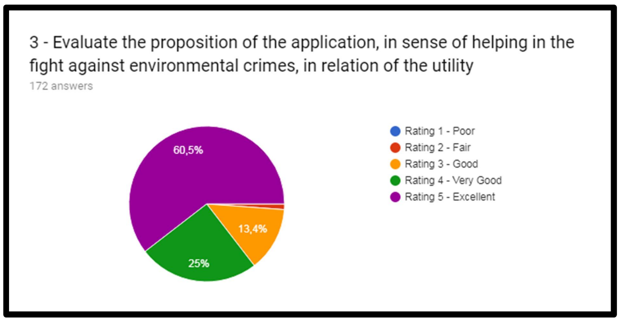

Figure 4. Answers to the third question on the form.

The fourth question attempted to verify the time taken to accomplish a denunciation, i.e., whether it would be faster in this project presented, the Preserve.TO mobile application, than in traditional methods, such as carrying out the denunciations through phone calls to the call centers, denunciation recipients, or even in person at the regulatory agencies. Thus, it was found, as shown in Figure 5, that 49.4% of the interviewed answered that the denunciation process would be fast, and only 7% of the interviewed answered that the agility in the denunciation process would be Fair, 9.9% answered “Good” and 33.7% answered “Very Good”. From these results, a sampling error of 0.0684% for each response, a standard deviation of 0.98981% and a variance of 0.8066% were obtained.

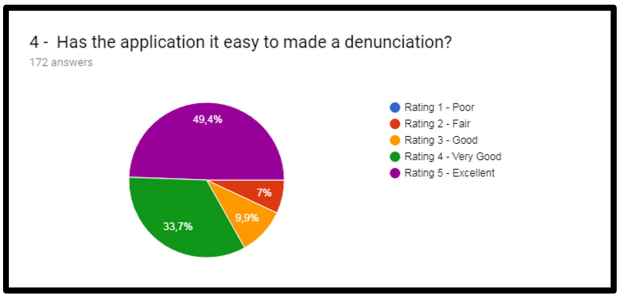

Figure 5. Answers to the fourth question on the form.

Consequently, in the fifth question 59.9% of people considered the application as a way to speed the denunciation process, so that it can quickly reach the competent authorities and avoid further damage to the environment. 33.1% answered “Yes”, 4.1% answered “Maybe”, 2.3% answered “Not much” and 0.6% answered “No”, according to Figure 6. Regarding this, 0.0560% as sample error for each response, 0.7352% as standard deviation and 0.5406% as variance were extracted.

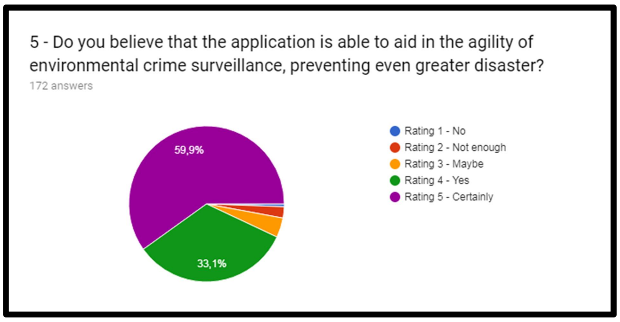

Figure 6. Answers to the fifth question on the form.

On the sixth question, 61% answered “Certainly” that technology can contribute to the preservation of natural resources by assisting inspection agencies with faster and more current information, promoting a better enforcement performance. 34.9% answered “Yes”, 2.3% answered “Maybe” and 1.7% answered “Not much”, as shown in Figure 7. With a sampling error of 0.0481% for each response, standard deviation of 0.6312%, and variance of 0.3998%.

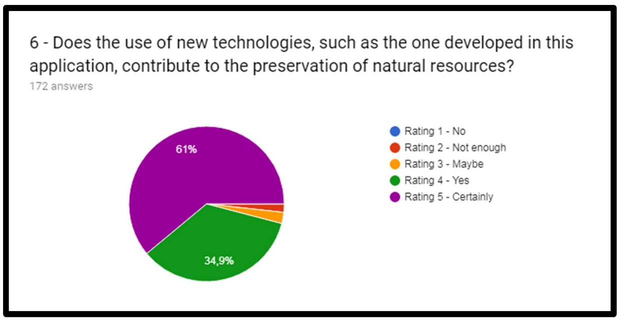

Figure 7. Answers to the sixth question on the form.

Finally, in the seventh question, Preserve.TO users were asked to recommend this project to be used by others, and 65.1% answered “Excellent”, 24.4% answered “Very Good”, 9.9% answered “Good” and 0.6% answered “Fair”, as shown in Figure 8.

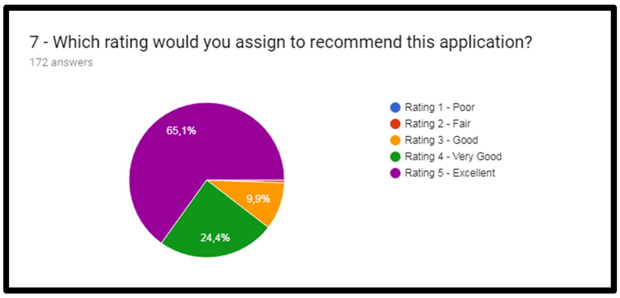

Figure 8. Answers to the seventh question on the form.

For this seventh question we have a sampling error of 0.0528%, standard deviation of 0.6934% and variance of 0.4809%.

VI. Conclusion and Future Research

This research is focused on how to develop useful data for someone and how to make this someone apply it. Bearing this in mind, we detect the need to preserve and care for something that is a well-diffused right, common to all citizens, which is the environment.

At the end of this research, through the data obtained, the researchers observed that the sample population that evaluated the application Preserve.TO believes that this tool will certainly help in preserving the environment. It will also enable a more agile reply from the public administration and will reduce bureaucracy in the current process of reporting environmental crimes.

According to the above, in the statistical data obtained in the data collection and illustrated in the above figures, it is observed that 94.2% of the sample believes that the application is capable of assisting in environmental preservation. Thus, still within the population, 89.5% of respondents believe in the relevance of the application to the environment in the current reality in which they live. These data reveal the acceptance of the application and reflect credibility that the population sample attributed to it, when they became familiar with it.

According to the data obtained in the research, on the proposition of the application to help reduce bureaucracy in the process of denouncing environmental crimes and assisting in the combat against crimes related to the environment, 60.5% of the interviewees rated the proposition as excellent, while 25% saw the proposition as very good. Therefore, it is observed that the proposition of the application was very well accepted by the population.

In the context of the easiness in conducting the denunciation process, 49.4% rated it as excellent and 33.7% rated it very good, which shows that the respondents believe in a greater efficiency of bringing a criminal complaint against the environment, using the application. So, within this process, the interviewees also believe that the application assists in the celerity of the entire procedure of reporting and monitoring environmental crimes, according to data obtained from the sample population, which indicates that 59.9% gave the maximum rating for the question, that is, they are sure that the application helps in dispatch. Still within this population, 33.1% answered “Yes”, believing also in the speed of the whole process.

The researched scenario, regarding the use of new technologies, shows that 61% of the those interviewed indicated the alternative “Certainly”, showing they believe in the use of new technologies such as Preserve.TO, while 34.9% answered “Yes”. So 95.9% of the sample population trust in the new application to help protect the environment.

Finally, it is noted in the statistical data, that 65.1% of the sample, that is, from the interviewees, checked the option “Excellent”, when asked, “Which rating would you assign to recommend this application?”, While 24.4% rated as “Very Good”.

Therefore, in this context, society believes that the Preserve.TO application meets the central goal of the research, which is how to generate useful information for someone and how to make someone else apply them.

Therefore, while it was understood that the Preserve.TO tool alone will not solve the environmental issue, it is nonetheless an important tool, which will assist environmental agencies in protecting the environment, informing environmental control actions, in order to investigate environmental infractions, increasing effectiveness in the protection of environmental resources by the public administration and society, punishing those responsible, as well as demanding compensation for environmental damage caused.

As a future study, this technological project can be used throughout the State of Tocantins, being extended to other states of the Brazilian federation, to assist in combating degradation to the environment. To that end, it will be available at the Federal Institute of Education, Science and Technology of Tocantins, Palmas campus, so that it can be continued and improved by interested parties or bodies responsible for fighting environmental crimes.

Currently the application contains a version for Android operating system, hosted in the Google Play Store. Therefore, to extend its use, other versions, for other platforms, can be developed. The popularization of this tool may also be carried out by means of communication in the media. According to the Federal Brazilian Law nº. 12.527/2011, which provides for the disclosure and publicity of actions of the independent public administration of requests, as improvements in the project, the implementation of functionalities is proposed, through which it is possible to follow-up the complaints made, so that the interested parties can accompany them, visualizing the progress made by the public administration, including the sanctions applied, whether the damage caused by the environmental crime has been repaired and other useful information [6].

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Blockchain and Its Impact on Telecom Networks

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Abstract - **For the last couple of years, Blockchain has been the most talked about technology across a range of industries, e.g., currency markets, banks and financial services, supply chain, logistics, manufacturing, etc. The telecom industry has also shown huge uptake for Blockchain-based solution. Plenty of use cases for telecom networks are already proposed and proof of concepts solutions are available via many vendors, operators, and telecom software companies. Identity management, Fraud prevention, Smart contract, Internet of Things (IoT) Security, Mobile data tokenization and Initial coin offering are some of the use cases which will be offered by telecom operators/companies in the very near future. This paper discusses in detail some of the important use cases and their implementation complexities. This paper also addresses how smaller or startup telecom companies/operators can leverage the Blockchain opportunity and disrupt the markets they are based in.**

Keywords-Blockchain; Consensus Methods; Communication Service Provider; Smart Contracts; Initial Coin Offerings.

I. INTRODUCTION

Blockchain is a decentralized and distributed ledger technology that uses algorithms and strong encryption to record digital transactions or data in a transparent, secure, and anonymous way [1]. Each block typically contains a hash pointer as a link to a previous block, a timestamp and transaction data. To put it very simply, Blockchain is a data-structure, like a linked list, where every new block of data is cryptographically linked to its predecessor (Figure. 1). By design, Blockchains are inherently resistant to modification of the data [3].

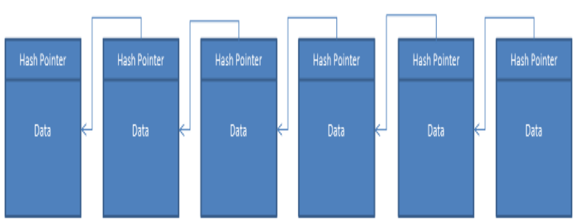

Figure 1. Simple visual representation of Blockchain.

As seen in Figure 1, this block of data has a unique hash which is the address or link to the next block. This chain of blocks is copied to all the peers of the network, making it distributed in nature, resulting in a chain of blocks known as Blockchain. This peer to peer architecture creates data redundancy, but ensures that there is no single point of failure, as shown in Figure 2.

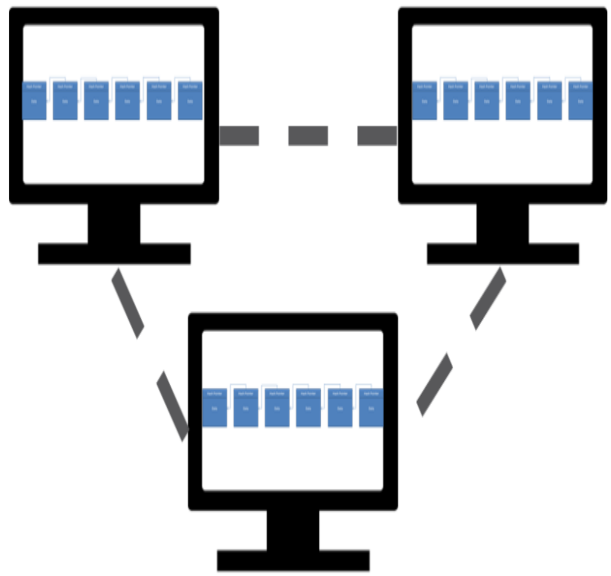

Figure 2. Peer to Peer distributed ledger architecture.

In this paper, we discuss basics of Blockchain technology, types of Blockchains, different consensus methods. We also suggest in the paper, plenty of Blockchain based use cases which can impact telecom networks. This paper also talks about how startups or incumbent operators can utilize this Blockchain opportunity and disrupt the economic and business model of the telecom industry.

The remainder of the paper is organized as follows: Section II talks about work done previously on this topic and our proposals. Section III describes types of Blockchains and compares their characteristics. Section IV deals with various consensus methods used in the network. Each consensus mechanism has its own pros and cons. We will propose multiple telecom use cases based on Blockchain in Section V. Section VI deals with business impact of Blockchain for startups and small operators. We conclude our paper in Section VII.

II. RELATED WORKS

Many telecom related use cases based on Blockchain have been proposed by operators, vendors, and different

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consultants [1][2][4]. Very few of these proposed use cases are under implementation. Some of them are either at proof of concept stage while others are still at proposal stage. As part of our work for this paper, we researched many use cases and their feasibility. We are also proposing new use cases which will help operators in monetizing Blockchain in telecom networks. Since Blockchain deals with trust and security so cases related to identity management, IoT security, local and global registries containing subscriber/device data and telecom network transactional records are best fit for early Blockchain based use cases in telecom.

As part of our study during this work, we have found that use cases monetization will help the operators reduce the operational expenditure and will open new sources of revenue generation as seen in Section V.

III. TYPES OF BLOCKCHAINS

Blockchain can be classified into public, permissioned and consortium Blockchain depending how it is accessed and how the access permissions are granted [3].

A. *Public Blockchain*

A public Blockchain is a Blockchain that can be accessed by anyone (often, anonymously). There are no restrictions on who can join and what transaction they can post if the transactions are mathematically valid. Although members can join the network anonymously (revealing only their public key), every transaction that they undertake is visible to everyone (public), which can be carefully studied to identify the users. Bitcoin is the most famous example of public Blockchains [3].

In such a network, there is typically an incentive given to the participants for executing a computing resource intensive consensus protocol (e.g., validate a block using Proof-of-work).

B. *Permissioned Blockchain*

A permissioned Blockchain is one in which the interaction within the business is restricted to users who have the access rights provided by the network owner/s. In such a network, non-anonymous validation of blocks or interaction with the Blockchain is not permitted. Usually, a Certificate Authority (CA) is used to manage access to such a network. A Blockchain platform running its network as a permissioned network, will determine who can be validators and what privileges are given to what users. Hyperledger Fabric [6] is one of the most prominent example of a permissioned Blockchain framework.

C. *Consortium Blockchain*

It is possible that a single (originating) organization will maintain the Blockchain (centralized) and provide predefined access rights to interacting parties. Such a network typically suits government or regulatory bodies who have legal purview over other participants. However, it is debatable whether to call such a network a Blockchain network, as the ledgers are stored centrally and are not distributed among participating nodes. A consortium Blockchain provides some of the benefits affiliated with permissioned Blockchain—efficiency and transaction privacy, for example—without consolidating power with only one company.

Figure 3 provides key characteristics of a Blockchain based network.

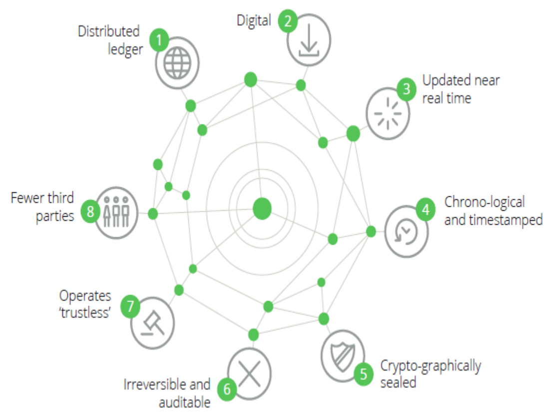

Figure 3. Key features of a Blockchain network [2].

IV. CONSENSUS METHODS

Consensus is a mechanism by which all nodes in the Blockchain network agree upon which block (transaction) gets added to the chain. Distributed computing existed well before Blockchains, but it is these consensus mechanisms which ensures that all the nodes in the network agree which makes the Blockchain so robust.

The ability to create honest self-correcting systems without the need of third-party to enforce the rules is what makes Blockchains so powerful. To enforce the rules, several variations of consensus algorithms/protocols are used, each with their pros and cons.

A. *Proof of Work (PoW)*

The most famous consensus algorithm is Bitcoin's Proof of Work (PoW), which make sure that the subsequent blocks in the chains are the only true versions. The correctness of the transactions can be verified by any participant using network consensus methods and cryptographic technologies in the Blockchain network. So, effectively the trust is established continuously within the network and not by any external central authority or auditor.

The Proof of Work protocol involves the following:

a) The miners solve cryptographic and complex puzzles to "mine" a block.
b) These puzzles are designed in such a way which makes it hard and taxing on the system as the

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process requires immense amount of energy and computations usage.

c) After solving a puzzle, the miner must present the block to the network for verification. Then, it is concluded whether are not this block belongs to the chain, which is not a simple process.

B. Proof of Stake (PoS)

Proof of Stake (PoS) is ideologically different from PoW, wherein the complete mining process is done virtually and the miners are replaced with validators. The validators must lock up some of their coins as a stake before the validation process is begun. During the validation process, if a block is discovered which they think can be added to the Blockchain, it would be validated by placing a bet on it.

If the block's validation is successful, the block gets appended and the validators get a reward which is proportionate to the bets they placed.

C. Proof of Activity (PoA)

Proof of Activity (PoA) is a hybrid approach that combines the previous two consensus algorithms namely PoW and PoS. Here, the mining is commenced in the traditional Proof-of-Work way, where the miners compete to solve a cryptographic puzzle. Importantly, here depending on specific implementations, the 'mined blocks' does not contain any transactions but are more like templates. The successfully mined and validated block contains only a header and the miner's reward address.

D. Proof of Burn (PoB)

As can be derived easily, the first three consensus algorithms are quite resource-intensive, both computationally, financially, and energy-wise (massive electricity used for upkeep of expensive computer hardware and Application Specific Integrated Circuit or ASIC cards). To circumvent this drawback, the Proof-of-Burn (PoB) algorithms lets you 'burn' the coins by dispatching them to irretrievable addresses. The miners are selected randomly to mine on the system. Depending on the implementation, the miners may burn the native currency or the currency of alternative chain such as Bitcoin. The miners have better chance of being selected to mine the next block depending on how many coins they have burnt.

E. Proof of Capacity (PoC)

All the previous algorithms employ a variety of 'Pay-to-play' schemes where miners either have to solve a hard cryptographic puzzle, or give coins in stake, or burn some coins. Proof-of-Capacity is also in similar lines in that here we have to 'pay' with hard-disk space. The ones with more hard-disk space at stake have better chances of mining the next block to earn the reward.

The Proof-of-Capacity algorithm generates large data sets known as 'plots' before the mining process, which are stored in the hard-drive. The more plots available on the hard-drive, the more chances to find the next block in the Blockchain.

F. Proof of Elapsed Time

To come up with more energy efficient algorithms, chipmaker Intel pioneered an alternative consensus protocol called Proof-of-Elapsed time. Here, instead of having participants solve a cryptographic puzzle, this algorithm uses a Trusted Execution Environment (TEE) to ensure that the blocks are produced in a random lottery fashion, but without the required work and hence less resource-intensive.

Table 1. below provides a comparison between different consensus methods.

TABLE I. DIFFERENT CONSENSUS METHODS

Consensus Algorithm	**Brief Description**	**Pros/Cons**
Proof of Work (PoW)	Nodes must solve complex cryptographic puzzles to get the right to append new blocks to the chain and get the rewards.	Pros: Being the first algorithm, it's currently the most popular. It's also highly scalable, which makes it attractive. Cons: Resource- intensive (Computational, financial, energy). Vulnerable to "51% attack"
Proof of Stake (PoS)	Validators lock up some of their coins as stake after successful validation block is added to the chain.	Pros: No need to solve complex cryptographic puzzles. Fast, efficient and uses less hardware Cons: Vulnerable: Someone with enough money to invest exclusively into the destruction of this system can do so by investing only

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		money, as opposed to PoW where they should invest money, time, expertise, hardware, electricity, etc.
Proof of Activity (PoA)	Hybrid approach combining PoW and PoS. The successfully mined and validated block contains only a header and the miner's reward address.	Pros: Combines best features of both PoW and PoS Cons: Less resource-intensive (Computational, financial, energy)
Proof of Burn (PoB)	Nodes must send their coins to an irretrievable address to mine a new block. The miner sending the largest number of coins get the chance to mine a new block.	Pros: No need to solve complex cryptographic puzzles. Cons: Burning coins is expensive as there is loss of coins. Less resource intensive.
Proof of Capacity (PoC)	Large number of plots generated in hard disk on stake, to get the right to mine the next block.	Pros: Miners does not need specialized hardware to mine. It decentralizes the mining process. Cons: Need lots of hard-disk space
Proof of Elapsed Time (PoET)	All nodes receive different waiting time duration, and the node with shortest duration will mine a new block.	Pros: Highly energy efficient as no cryptographic puzzle to be solved. Cons: Reliance on third-party (Intel). Relies on specialized hardware

V. TELECOM USE CASES

A. Identity and Data management

Identity and data management is a big use case for Blockchain which the telecom companies can use to generate new sources of revenues. Operators could provide their subscribers with an embedded SIM (eSIM) or app that creates unique virtual identities for each subscriber which are encrypted and stored in a Blockchain. Subscribers can use this identity to automatically authenticate themselves when visiting e-commerce websites, secure buildings, smart vehicles, airplane tickets, and so forth, as well as verification of personal documents such as passports, driving licenses, birth and marriage certificates, and educational degrees. For example, a virtual identity stored in a Blockchain using the operator's app could be used by a subscriber to sign into Facebook or Google on a mobile device. The benefit of having such a service is that the subscriber doesn't need to provide his or her personal details to different service providers to create new accounts and complex passwords. The virtual identity stored through the operator's app could be provided to numerous partner websites, utility service providers and apps as a unique identifier [1]. People will much more easily try new services if they do not have to subscribe from scratch –logging in with your Google/Facebook account is the best example of this.

This use case will open new sources of revenue for the operators and could be a game changer in how we access third party sites, apps, government facilities etc. In fact, United Nations is already working on a project called ID2020 [7] which is a public private partnership dedicated to providing identity services to the one billion people who live without an officially recognized identity and Blockchain is a key technology for this project.

B. IoT Smart contracts

A smart contract is a protocol used to facilitate and verify the negotiation of a contract. Just like a physical contract, smart contract defines the rules and penalties around the agreement, but it can also automatically enforce them. Industries like insurance, legal services, financial services, asset management use smart contracts to enforce rules and protocols. For telecom industry, Internet of Things (IoT) is one area where Blockchain based smart contracts could be extremely useful.

One of the biggest issues in IoT is how to maintain trust and security among millions (if not billions) of sensors that are getting connected with the network. The devices in the IoT ecosystem are the points of contact with the physical world. When IoT platforms use a Blockchain based solution for connectivity/authentication, time-consuming workflows can be automated in new and unique ways, achieving cryptographic verifiability, as well as significant cost and time savings in the process.

C. Decreasing OPEX by proactively using transactional network profile

Telecom operators can save millions of dollars of Operational Expenditure (OPEX) by using transactional network profile to proactively identify and resolve potential network issues. Proactive customer retention efforts are kind of process enhancements, service improvements and quality initiatives that encourage loyalty by removing the causes of defection in the first place. Decreasing OPEX by proactively using transactional network profile will also help in:

a) Debugging call related issues
b) Identification of degraded cells

c) Anomaly detection
d) Compliance and regulatory checking in future
e) Reducing fraud between collaborating operators

Currently, the primary reason for the increase in churner rate is the degradation of quality. Quality degradation could be because of frequent dropping of calls or lack of throughput. In most of the cases the operators are not aware of the issue. Either there is excessive load on the cell or there is configuration mismatch or software issue. As the operators rely on alarms for action and in most of the situation there is no alarms generated for these scenarios.

Blockchain can help in storing network transactional data. The persisted data can be studied further to detect degraded services, their patterns from the past, and reasons behind those patterns. Important Performance Monitoring (PM) counters related to cells e.g., Radio Resource Connection (RRC) connection successes, throughput across a cell for weekday and public holiday can be stored on a Blockchain based records. This trend could be compared with the current trend of a cell. If the variance is quite high, operator could be alerted about the cell. Operator can then proactively take action so that customer's experience is not degraded. Even the operator's customers could be informed of the potential issue enhancing the trust further.

D. Initial telecom/network coin offerings

Initial Coin Offering (ICO) has been a buzzword for the last couple of years due to the emergence of so many cryptocurrencies in recent past. For the uninitiated, ICOs are means of crowdfunding a new cryptocurrency or Blockchain based startups. Now, even telecom based companies have started to issue telecom/network related coins. The ICO are normally related to public Blockchain-based systems that anyone can participate in and so are the "coin offerings".

The main rationale behind these network coin offerings is that the it allows different models of monetization with pricing being governed by external factors rather than telecom operators or service providers. ICOs are good way of tokenizing mobile data, voice, app based packages and other network capabilities.

E. Mobile data tokenization

Mobile data plans are normally moderated by operators with unused data expiring at the end of every billing cycle in most parts of the world. Mobile data rates vary from 1$/GB to 10$/GB across different operators and regions. Millions of dollars of unused data expire every month across the world. Even with more than 2 decades of mobile connectivity, more than half of the world's population still does not have mobile and data connectivity. The unused data could be provided to underprivileged or unconnected parts of the planet thereby providing data connectivity.

A simple Blockchain based exchange could help to bridge this gap whereby users can donate or sell their unused data plans in the form of tokens to other users. A decentralized solution for providing mobile data will enable recipients to buy from providers at transparent terms, and reduces costs than buying from operators. The use case will require partnerships with operators to offer mobile data packages and enable user-to-user data transfer.

F. Global and country-specific registries

These registries could be databases both short and long term where information may get updated once in a week, month, or year. These registries could contain lists of blacklisted customers, lost devices, number portability updates and shared spectrum usage rights and allocations. Blockchain-enabled trust and security will be the most important differentiating factors which will keep these registries different from normal databases and will be accessible to different operators. Cross operator registry having International Mobile Equipment Identity (IMEI) of lost mobiles can be used for identifying and location lost devices. Of course, these registries require a lot of collaboration among the operators along with regulatory framework put in by regulatory body.

In fact, in May 2018, Telecom Regulatory Authority of India (TRAI) has proposed the use of Blockchain based ledger to curb the menace of spam or unsolicited commercial communication (UCC).

VI. How starts ups , small operators can leverage upon Blockchain opportunity

Blockchain is one technology which could be compared to dot com boom of the late nineties. Blockchain has the potential to disrupt telecom industry in a big way. Different startups can specialize with innovative Blockchain solutions for facets such as virtual SIM card provisioning, authentication, national and international roaming solutions, micro-payments, customer care, data storage on a common cloud across operators.

Also, the backend operations, such as Operation Support System (OSS) and Business Support System (BSS) processes like billing of consumers, validation and number portability databases can be improved upon using block-chain. Dent wireless [8] and Airfox wireless [9] are two such startups which are disrupting the telecom data markets by their unique offerings. Mobile Virtual Network Operators (MVNO's) and tier 2-3 operators can also make use of this unique opportunity by offering innovative solutions based on Blockchain and challenge the big operators.

VII. Conclusion

Blockchain has been most talked and hyped technology of recent years with use cases coming out in almost every domain. Although Blockchain in its initial years had been centered around currencies, banks and insurance sectors now industries like telecom see greater value from Blockchain implementation. Trust and security are important from the telecom network point of view. Blockchain presents a possible use case due to its inherent characteristics, especially in use cases where a third party is involved.

Blockchain will also enable new data monetization plans, enterprises will come up with innovative business models challenging and disrupting the traditional models employed by many of the telecom operators. It is expected that within the next few years, the use of Blockchain technology by the telecommunications industry will become more widespread and eventually become the norm in services like identity management, and registries to start with. As is often the case with any new technology, Blockchain is being developed and implemented at a faster rate than the existing regulations and government's frameworks. Regulatory authorities should also enable flexible legal and specification frameworks, such as data protection laws, for faster implementation of technologies such as Blockchain in telecom.

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DISCLAIMER

This paper reflects the authors own opinions and not necessarily those of their employer.

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A Modern Quality of Service Evaluation Approach of VOLTE Calls Focused on Packet Delays

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Abstract — **Long-Term Evolution (LTE) coverage in mobile networks is becoming more widespread day by day. As a consequence of this situation, Voice over LTE (VOLTE) calls in LTE networks have increasingly become more important compared to traditional Circuit Switch (CS) voice calls. Also, smartphone usage grew rapidly in the last few years and VOLTE support is a vital feature of smartphones. Additionally, Mobile Network Operators (MNO) tend to promote VOLTE service since VOLTE technology has lower operational costs than traditional voice service in the long run and promises improved sound quality. Although there are several straightforward Key Performance Indicators (KPIs) such as call drop rate, jitter, packet delay, packet loss rate, etc. in order to measure VOLTE quality of service, evaluation of the measured values and revealing real perceived quality of service by subscribers is complex. Experienced VOLTE quality of service value depends on many factors. Determining factors and their significance is central to measuring and improving perceived VOLTE quality of service. This paper deals with the evaluation problem and proposes a new approach to evaluate perceived VOLTE quality of service experienced by subscribers.**

Keywords— Expected quality of VOLTE call; evaluation approach; packet delay; user experience; perceived quality.

I. INTRODUCTION

It is generally believed that communication between people far away started with smoke in the very early ages. Centuries later, the telegraph appeared as a crucial invention in peoples' lives. In the following decades, other new types of communication devices and technologies were invented such as the telephone, the radio, the computer, the Internet and the cell phone. Finally, smartphones were produced and have become widespread, which was the beginning of a new smart era. In this era, people increasingly tend to use smartphones as small pocket computers and access the Internet with their mobile devices mostly using the Global System for Mobile Communications (GSM) network.

In the smartphone era, almost every person owns a smartphone in order to increase their life quality. Some people use it for its original purpose, which is connectivity, but now smartphones have become more than that: they can be used for social media, navigation, gaming, business, and even health. People can also customize their smartphones according to their needs.

Intensive smartphone and mobile application usage fall short in fulfilling people's download and upload needs. As a result, 4G or LTE technologies have been proposed for data access. Since LTE is an advanced technology and allows higher data consumption and speed, traditional voice calls became less important. Instead, VOLTE technology was invented which can enable better sound quality. VOLTE is a Packet Switch based technology, which differs from the traditional Circuit Switch voice infrastructure.

VOLTE is becoming more popular day by day. MNO companies also encourage customers to use VOLTE for better user experience and lower infrastructural costs in the long term. VOLTE holds the promise of providing users with clear, high-definition call quality combined with much greater spectral efficiency and capacity compared with conventional circuit-switched calls over legacy 2G and 3G networks [4]. This means that it is easier for a caller not only to hear clearly what the person at the other end of the line is saying, but also to detect their tone of voice, giving a much richer overall experience. Global System for Mobile Communications Association (GSMA) announced that, by February 2018, 127 Mobile Network Operators in 63 different countries launched the VOLTE service. Also, there are more than 1218 mobile phone models that support and are ready to use VOLTE services [5].

There are several straightforward KPIs including call drop rate, jitter, packet delay, packet loss rate measuring VOLTE quality of service. But evaluation of measured values and hitting perceived quality of service by subscribers is difficult and these KPIs are not sufficient by themselves. Additionally, there is no globally accepted standard process for this purpose.

In this paper, the problem of VOLTE quality of service evaluation is discussed in detail. Previous market insights and measured values are combined in order to propose a modern approach to solve this problem. Finally, an expected call delay approach is devised and the approach is tested, which leads to successful results.

The rest of the paper is structured as follows. In Section II, we present the problem definition, including supportive figures. In Section III, exploratory data analysis and data preparation are performed. In Section IV, factors affecting experienced call delay by GSM subscribers are investigated in detail. Finally, our work is concluded in

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Section V and future directions are discussed in Section VI.

II. Problem Definition

As VOLTE technology is becoming more widespread and gradually replaces traditional voice service, measuring VOLTE and improving quality of service has become a standard requirement for GSM companies. In fact, the traditional approach that is measuring call drop numbers and rates is still valid, but it does not provide continuous scoring of perceived quality of service. Since a call is either dropped or it succeeds, there is nothing to measure between these two extreme sides. Therefore, call drop is not considered in the scope of this study.

The Mean Opinion Score (MOS) method is another voice quality scoring method, which has been used for decades. In MOS method, subjects judge and score the quality of voice ranging from 1 (lowest quality) to 5 (highest quality). An average MOS value is derived from individual subject scorings. However, using the MOS method in the telecom industry has a limitation, namely, it is unclear what threshold values should be applied to identify problems or determine acceptability [3]. Which MOS value is good, or good enough? It is difficult to find the correct threshold value.

VOLTE technology is a packet switching based technology so, generally, KPIs used in data service are also valid for VOLTE service. The most commonly used KPIs for measuring VOLTE quality of service are jitter, packet loss ratio and packet delay during a VOLTE call [1].

Packet delay, which is also called latency in some resources, is the total time it takes a VOLTE packet to travel from a source location to a destination location. Jitter is a measure of fluctuations in packet delays during a VOLTE call. Lastly, packet loss ratio is the ratio of the number of packets that are completely lost and never reached the destination versus the total number of packets sent [8].

Since networking has improved over time and VOLTE is an evolved technology, packet losses, and jitter problems are handled successfully in modern networks. But packet delays still remain a big issue because packets must physically travel from a source location to a destination location and an acceptable travel time should be guaranteed. Among these three basic KPIs, packet delay is used in the scope of this study in order to model user experience.

In the remaining part of the article, we use the term call delay to denote the average of all packets' delay belonging to a single VOLTE call. Although it is easy to define and calculate call delay, it is not so easy to evaluate measured call delay values. It is a complicated issue to make inferences from measured call delay values. As an example, is the measured experience of 300 milliseconds call delay acceptable? What about 250 milliseconds call delay? Is it a good experience or bad experience?

The main problem is that evaluation of measured values (such as 300 milliseconds) is not straightforward and there is no globally accepted reference point. In fact, worldwide references may also not give us the real picture, because each VOLTE network of each Mobile Network Operator has its own parameters, settings and establishment. In order to overcome this evaluation problem, one common methodology is comparing individual subscriber's call delay figures with the whole network's averages.

Fig. 1 shows the average call delay values measured in Turkcell mobile network in November 2017. Because of market competition and commercial limitations, exact call delay values cannot be revealed. Instead, values are multiplied by a private multiplier and general trend is depicted. The unit of multiplied call delay values is defined as "D" in the remaining part of this paper. Regarding Fig. 1, average call delay values vary daily and it is difficult to interpret this figure in terms of experience evaluation. Comparing individual subscriber's call delay figures with the whole network's figure will be a misleading approach.

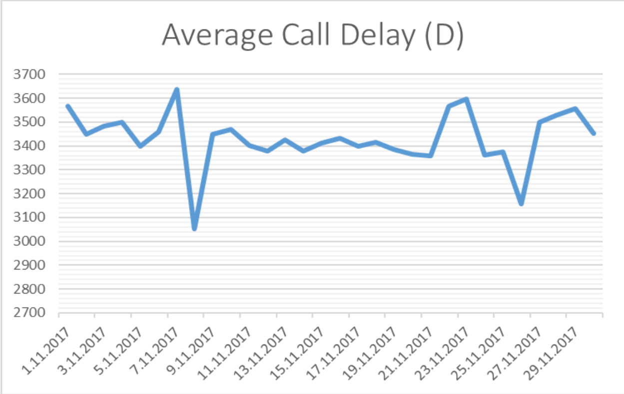

Fig. 1. Daily average call delay trend of the whole network

Another common methodology is the location-based comparison, where individual subscriber's call delay figures are compared to his/her city or district's call delay figure. As we mentioned previously, these simple methodologies may result in wrong interpretations. VOLTE experience should be evaluated call by call and generalizations will lead to incorrect results.

III. Exploratory Data Analysis & Data Processing

VOLTE call analysis data set is selected as November 2017 when VOLTE usage maturated as a major service for Turkcell in Turkey. Fig. 2 shows the daily trend of VOLTE call numbers. Monthly total number of calls is 302.673.551 which is pretty huge data.

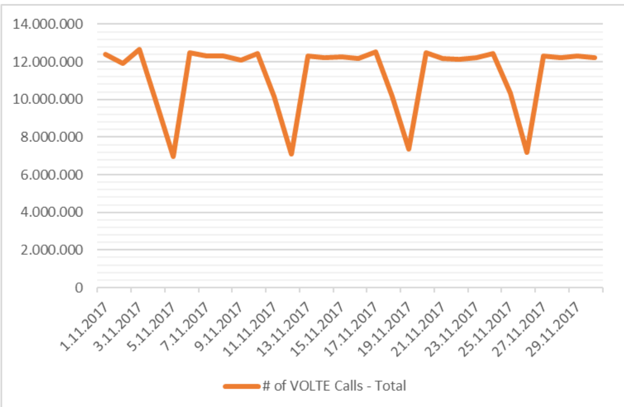

Fig. 2. Total VOLTE call count trend

Since this article is focused on continuous VOLTE call scoring and detection of affecting factors, all VOLTE calls should not be directly included in the detail analysis set. Firstly, VOLTE calls targeted to other Mobile Network Operator and originated from other Mobile Network Operator should be eliminated because other operator's network settings may be different. Secondly, dropped calls should be eliminated because they present bad extreme experience and may mislead the study. Fig. 3 shows VOLTE call numbers daily trend after this reduction and monthly total number of calls became 178.350.133.

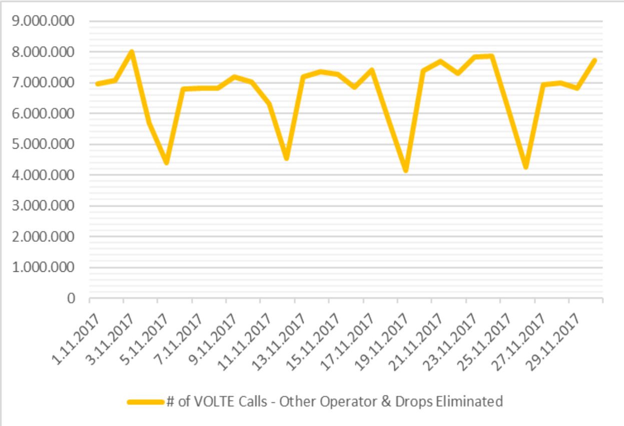

Fig. 3. Reduced VOLTE call count trend

As a rule of basic statistics, outliers are detected and eliminated from data set. In order to eliminate outliers, first standard deviation (σ) is calculated as 1.571,33 D and mean (μ) is calculated as 3.286,77 D. Values greater than $\mu+3\sigma$ and less than $\mu-3\sigma$ are accepted as outliers and removed from data set. Fig. 4 shows VOLTE call numbers daily trend after outlier elimination and monthly total number of calls became 174.783.131. It seems that the general trend behavior did not change after filtering operations.

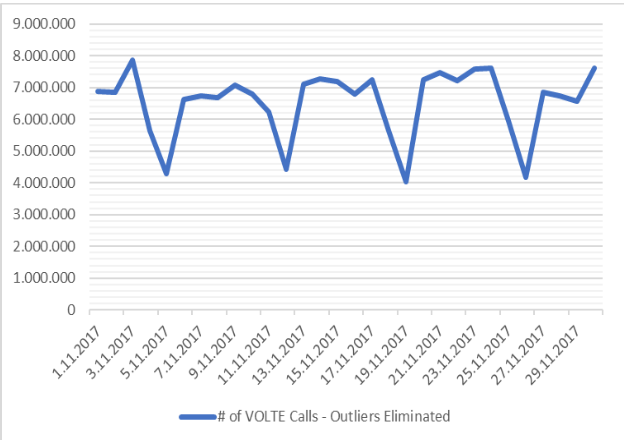

Fig. 4. Outlier eliminated VOLTE call count trend

Fig. 5 shows call delay histogram, which can be assumed as a normal distribution.

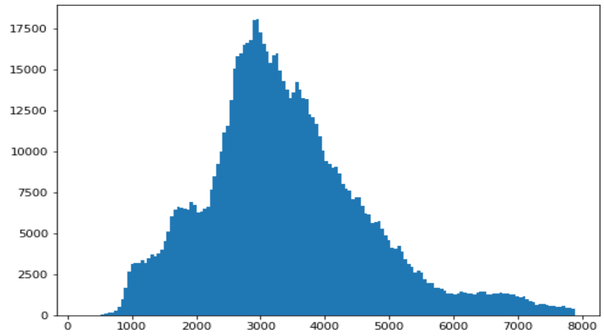

Fig. 5. Call delay histogram

IV. INVESTIGATION OF FACTORS

In this section of the article, investigations of various factors that are assumed to affect perceived VOLTE quality of service of subscriber are performed.

First, the distance between caller subscriber and called subscriber must be the dominant factor affecting transmitted packet delay. By nature, data packets propagate physically through the network and arrive at the end point. The distance is assumed as geographical distance as the crow flies between attached base stations of caller subscriber and called subscriber. This distance is named as call distance in the remaining of this article and it is measured in kilometers.

Fig. 6 shows the average call delay correlation analysis with the distance between attached base stations of caller subscriber and called subscriber. Not surprisingly, average call delay and call distance are strongly correlated with Pearson r coefficient equal to 0.71 [6]. So, it is proved that distance between attached base stations of caller subscriber and called subscriber is a major factor affecting experienced call delay.

Correlation analysis and visualization depicted are performed using Python's Pandas, Seaborn, Matplotlib and Numpy packages.

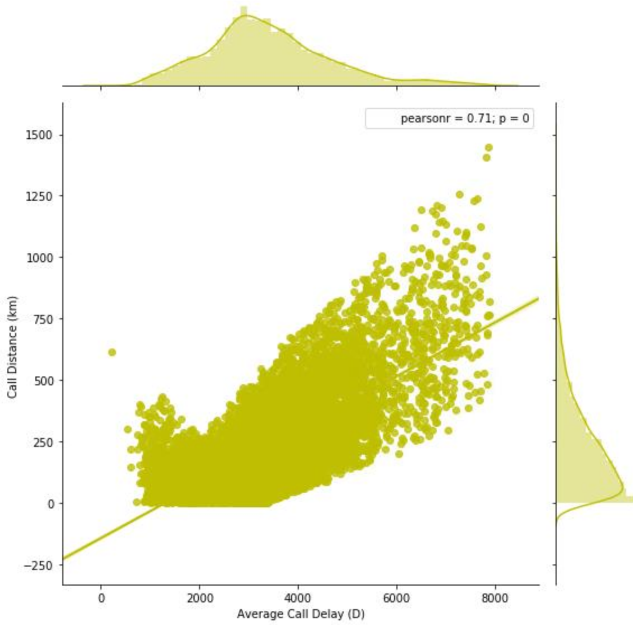

Fig. 6. Correlation and effect of call distance

Second, audio codec used may be another important factor affecting experienced call delay in November 2017. Fig. 7 shows the average call delay trend of AMR and AMR Wideband codec types. In Turkcell VOLTE infrastructure, these two types of codec are used for VOLTE service. Average call delay of AMR Wideband codec is absolutely higher than AMR codec. Therefore, codec type is another factor affecting experienced call delay.

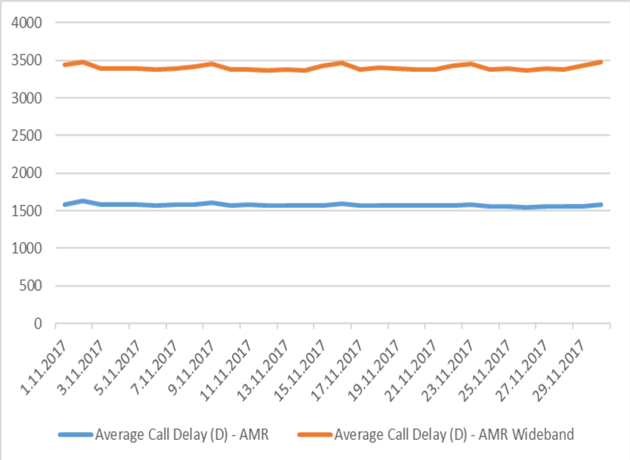

Fig. 7. Effect of audio codec used

Another factor may be the duration of VOLTE call. Since call duration is continuous data set, statistical analysis is performed and percentile results are given in Table I [2]. Call durations divided into three main groups as Short, Normal, Long using division points at 33rd percentile and 66th percentile.

TABLE I. CALL DURATION PERCENTILES

Percentile	*Call Duration (Sec)*
Minimum	0,5
1th percentile	4,1
25th percentile	21,9
33rd percentile	27,4
50th percentile	38,5
66th percentile	57,2
75th percentile	77,8
99th percentile	890,4
Maximum	7.235,1

Fig. 8 shows the call delay trend of clustered call durations in November 2017. In this figure, the first finding is that short calls significantly has lower average call delay than other two clusters. Long calls have higher average call delay than normal calls in general. However, there are some fluctuations and in a few days normal calls have a bit higher or close averages than long calls. Although there are few extreme cases, call duration is positively correlated with call delay, so call duration category is a factor affecting experienced call delay.

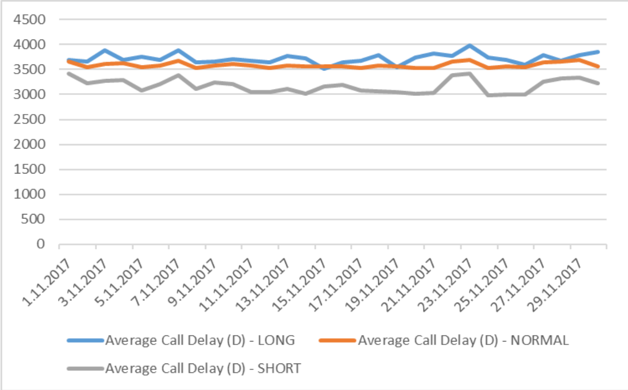

Fig. 8. Effect of call duration category

Mobile devices that are mostly smartphones vary in terms of hardware features such as CPU, storage, memory, camera. These physical features affect the responsiveness of the phone in other words user experienced speed when some action is triggered. Similar to traditional computers mobile devices have their own operating system. Most widespread ones are IOS and Android. Also, some other less used operating systems exist such as Windows 8, Symbian, etc.

Since operating system controls every process executed in a mobile device, type of operating system may be another factor affecting VOLTE quality of service. Fig. 9 shows the average call delay trend of VOLTE calls grouped by mobile device operating system of caller subscriber in November 2017. Less used operating systems are grouped as other in statistical analysis. As depicted in the figure, Android operating systems have minimum average call delay almost every day whereas other operating systems have the higher call delay. Other operating systems have higher average call delay than IOS. It should also be noted that other operating systems' average call delay trend is not steady and is very fluctuating. Therefore, mobile device operating system of caller subscriber is a good factor in experienced call delay.

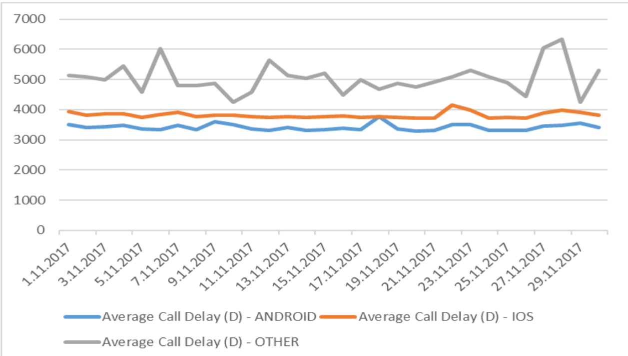

Fig. 9. Effect of mobile device operating system of caller subscriber

Similar to mobile device operating system of caller subscriber, mobile device operating system of called subscriber should be another variable to be investigated. Fig. 10 shows the average call delay trend of VOLTE calls grouped by mobile device operating system of called subscriber in November 2017. As depicted in the trend graph, mobile device operating system of called subscriber is also determining factor in experienced call delay.

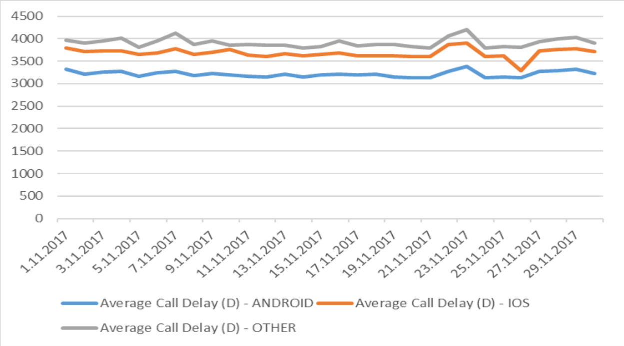

Fig. 10. Effect of mobile device operating system of called subscriber

During the investigation of factors, it is revealed that the more mobile subscribers are the worse quality of service they experience. Fig. 11 shows the call delay trend of VOLTE calls grouped by caller subscriber mobility in November 2017. It is obvious that VOLTE calls of moving subscribers have higher average call delay than VOLTE calls of not moving subscribers. Therefore, the mobility of caller subscriber is an indirect but a significant factor affecting experienced call delay.

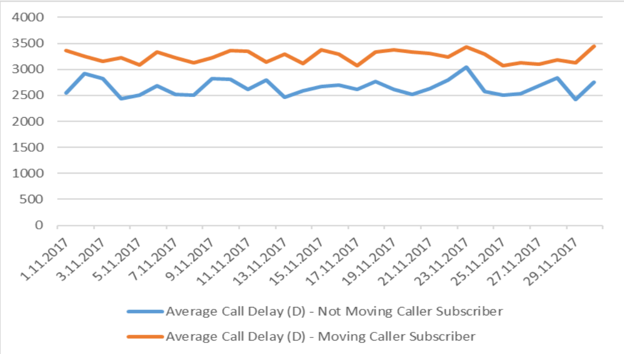

Fig. 11. Effect of mobility of caller subscriber

Since a call is two ended concept, if the mobility of caller subscriber affects VOLTE experience, it is expected that the mobility of called subscriber should also affect it.

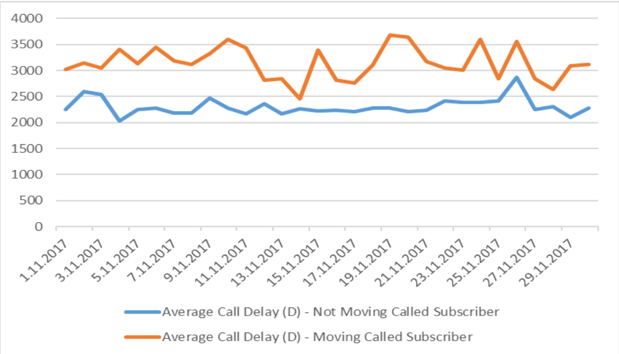

Fig. 12. Effect of mobility of called subscriber

Fig. 12 shows the call delay trend of VOLTE calls grouped by called subscriber mobility in November 2017. The average call delay of moving subscriber is apparently fluctuating. But there is no doubt that VOLTE calls of moving called subscribers have higher average call delay than VOLTE calls of not moving called subscribers. As a consequence, the mobility of called subscriber is an indirect but a determining factor affecting experienced call delay.

V. Proposal of New Approach

In the previous section, we have proved that experienced call delay depends on numerous factors which are:

- Audio codec used (AMR, AMR Wideband)
- Call duration category (Short, Normal, Long)
- Mobile device operating system of caller subscriber (Android, IOS, Other)
- Mobile device operating system of called subscriber (Android, IOS, Other)
- Mobility of caller subscriber (Moving, Not Moving)
- Mobility of called subscriber (Moving, Not Moving)

When VOLTE quality of service experience is simplified down to call level, similar to data sessions [7], each call has unique characteristics formed by 6 major factors mentioned above. In other words, either AMR or AMR Wideband is used in VOLTE call. Similarly, caller subscriber is either moving from one point to another point or is not moving (remain in a fixed location) during a VOLTE call.

TABLE II. SAMPLE CHARACTERISTICS

VOLTE calls	***Audio codec***	***Call duration category***	***Mobile device operating system of caller subscriber***	***Mobile device operating system of called subscriber***	***Mobility of caller subscriber***	***Mobility of called subscriber***
VOLTE call 1	AMR	Short	IOS	Android	Moving	Moving
VOLTE call 2	AMR	Short	Android	Other	Not moving	Moving
VOLTE call 3	AMR	Short	Other	IOS	Moving	Moving
VOLTE call 4	AMR	Medium	IOS	Android	Not moving	Moving
VOLTE call 5	AMR	Medium	Android	Other	Moving	Moving
VOLTE call 6	AMR WB	Medium	Other	IOS	Not moving	Not moving
VOLTE call 7	AMR WB	Long	IOS	Android	Moving	Not moving
VOLTE call 8	AMR WB	Long	Android	Other	Not moving	Not moving

Table II shows 9 different VOLTE call characteristics as an example. Since the characteristic of a VOLTE call is formed by 6 major factors, we reach 324 (3x3x3x3x2x2) possible combinations, therefore 324 distinct VOLTE call characteristics.

Each of the 324 distinct session characteristics has its own conditions, dependencies and stories. We have come up with the concept of Expected Call Delay that is ideal delay value of any VOLTE call based on call

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characteristics. The formula for Expected Call Delay is devised as follows:

$$Expected\ Call\ Delay = K_i * Log\ (CD) \qquad (1)$$

where K_i is a constant value for related VOLTE call characteristic and CD is call distance. Call distance is the measured distance between two parties of VOLTE call, where actual coordinates of subscribers' attached base stations are taken into consideration. For each VOLTE call characteristic, a detailed statistical analysis is performed and constant K values are calculated separately. Basically, successful VOLTE call samples are taken into consideration. Actual call delay and call distance values can be measured from these samples. Then constant K_i values are calculated according to the proposed equation after basic statistic operations including outlier elimination. So 324 different K values are prepared for the equation.

For any VOLTE Call, Expected Call Delay is calculated by measuring the distance between calling and called subscribers, taking logarithm and then multiplying by related constant K value.

In order to test the success of proposed VOLTE quality of service evaluation approach, which is Expected Call Delay concept, real subscriber complaints are used as test set. Our test method was that whether the proposed approach could detect unhappy subscribers or not. Happy subscribers generally do not give feedback. In other words, happy subscribers do not tend to call GSM call center and thank for high level of quality of service. In the test, all subscribers who made a complaint about voice call related problems are taken into account. In order to make a correct correlation analysis, only VOLTE calls of the complaining subscribers before actual complaint time are included in the test set.

During the analysis, expected call delay values, according to the proposed approach, are calculated for each VOLTE call in the test set and compared with measured actual call delay values. Then, each call is classified as good, fair and bad experience based on the comparison of its actual call delay value and its expected call delay value. Table III shows classification details where ECD is calculated expected call delay value and ACD is measured actual call delay value of the related call.

TABLE III. CALL CLASSIFICATIONS

Rule	***Class***
ACD > ECD + (%5 * ECD)	Bad
ECD + %5 * ECD ≥ ACD ≥ ECD - %5 * ECD	Fair
ECD - %5 * ECD > ACD	Good

Results showed that our approach classified %87.77 of the calls as Bad experience, % 9.41 of the calls as Fair experience and %2.82 of the calls as Good experience. Therefore, 87.77% of individual subscribers who complained about voice calls have been classified as Bad experience within complaint period. As a result, it can be said that the proposed Expected Call Delay approach is successful in evaluating subscriber perceived quality of service and detecting Bad experience.

VI. CONCLUSION AND FUTURE WORK

This paper presented a detailed analysis on VOLTE quality of service measures and evaluation problem. Based on analysis results, a new concept of expected call delay was proposed and a formula was created.

The solution was easy to use and very practical in detecting individual subscriber's VOLTE quality of service perception. Initial success rate (which is 87.77%) of the expected call delay concept and formula to reflect the subscriber's perceived VOLTE service experience was very high.

Currently, the solution is applied to evaluate VOLTE service experience of a sample set of subscribers in Turkcell and an initial feedback on our solution is very positive.

In the future, there are several factors to be investigated whether they affect customer experience on VOLTE or not. Firstly, weather condition especially the average temperature and temperature changes during a day may be an important factor. Secondly, eliminated VOLTE calls originated from or terminated by other Mobile Network Operators should be investigated. Although other operator's network is another network and it has its own differential settings, this investigation may give some clues about customer VOLTE quality of service perception. Thirdly, the business of base station and attached cell of caller subscriber may be another factor. The simultaneous number of active VOLTE call at the same time may act as a factor. Similarly, the business of base station and attached cell of called subscriber may be investigated. Lastly, this study is conducted on one month's data. Although hundreds of millions of VOLTE calls are analyzed and a very strong proposal is formed, analyzing one or two year's data may give us more detailed results and idea about seasonality effect on VOLTE quality of service.

ACKNOWLEDGMENT

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Suboptimal Decoding Scheme Based on Parallel Detection for ATSC 3.0 MIMO System

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***Abstract*—This paper proposes a suboptimal decoding scheme based on QR-decomposition which means a decomposition of a matrix A into a product A=QR of an orthogonal matrix Q and an upper triangular matrix R and Parallel Detection (PD) for Advanced Television Standard Committee (ATSC) 3.0 Multiple-Input Multiple-Output (MIMO) system. The 2x2 complex-valued channel model of ATSC 3.0 MIMO system can be transformed into a 4x4 real-valued channel model. For the 4x4 real-valued channel model of ATSC 3.0 MIMO, PD-based decoding can reduce the decoding complexity with a negligible performance loss compared with the maximum-likelihood decoding.**

Keywords-ATSC 3.0; real-valued representation; MIMO precoding; parallel detection.

I. INTRODUCTION

In Advanced Television Standard Committee (ATSC) 3.0, Multiple-Input Multiple-Output (MIMO) is optionally supported and can provide spatial diversity and multiplexing gains [1]. The ATSC 3.0 MIMO system additionally includes MIMO demultiplexer and precoder compared to ATSC 3.0 baseline system. Each output of the MIMO demultiplexer is mapped to constellation symbols in the mapper which is identical to ATSC 3.0 Single-Input Single-Output (SISO) [2]. In ATSC 3.0, Non-Uniform Constellations (NUCs) are defined and the shape of NUCs is specified for each combination of modulation order and code rate [3]. Also, the MIMO precoder consists of the stream combining, I/Q (In-phase/Quadrature) polarization interleaving and phase hopping. Here, the precoder outputs can be divided into the in-phase and quadrature components and then the 2x2 complex-valued channel model of ATSC 3.0 MIMO system can be transformed into a 4x4 real-valued channel model [4].

This paper proposes a suboptimal decoding scheme based on QR-decomposition [5] and Parallel Detection (PD) [6] using the 4x4 real-valued channel model for ATSC 3.0 MIMO system. Since NUCs are used in ATSC 3.0, the shape of NUCs should be considered for the proposed decoding scheme. However, NUCs were not considered in previous works for real-valued channel models [7][8]. The proposed decoding scheme can reduce the decoding complexity with a negligible performance loss compared with the Maximum-Likelihood (ML) decoding.

The rest of the paper is organized as follows. Section II introduces the MIMO precoder and NUCs of ATSC 3.0. In Section III, the real-valued received signal model for ATSC 3.0 MIMO is described and the proposed decoding scheme is presented. The simulation result is provided in Section IV and finally, this paper is concluded in Section V.

II. MIMO PRECODER AND NUCS OF ATSC 3.0

The received signal vector of ATSC 3.0 MIMO system can be represented as follows:

$$\begin{bmatrix} U_{2i} \\ U_{2i+1} \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} S_{2i} \\ S_{2i+1} \end{bmatrix} + \begin{bmatrix} n_{2i} \\ n_{2i+1} \end{bmatrix} \qquad (1)$$

where $\mathbf{u}_i = [U_{2i} \quad U_{2i+1}]^T$ denotes the received signal for the i-th cell pair. And, $\mathbf{H} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}$ denotes the 2x2 complex-valued channel gain matrix and h_{mn} means the complex-valued channel gain between the n-th transmit antenna and the m-th receive antenna. Also, $\mathbf{N}_i = [n_{2i} \quad n_{2i+1}]^T$ denotes the Additive White Gaussian Noise (AWGN) vector for the i-th cell pair. Here, $\mathbf{s}_i = [S_{2i} \quad S_{2i+1}]^T$ denotes the output vector of the MIMO precoder for the i-th cell pair where the input

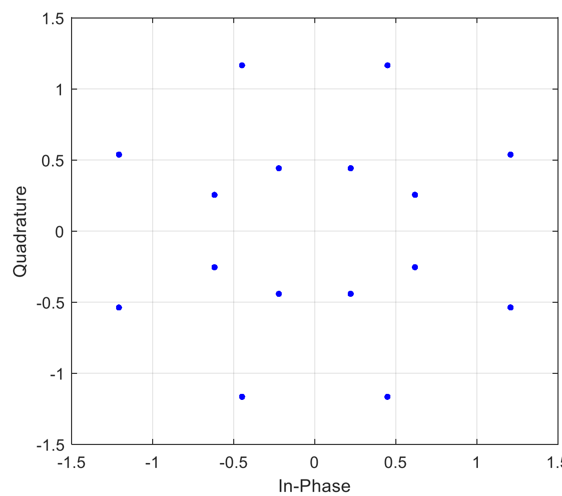

Fig. 1. Example of NUC for 16-ary modulation with code rate of 10/15

vector $\mathbf{x}_i = [X_{2i} \quad X_{2i+1}]^T$ is input into the MIMO precoder and passes through the stream combining, I/Q polarization interleaving, and phase hopping blocks in turn.

In ATSC 3.0, NUCs are used in the mapper. Fig. 1 shows an example of NUC for the combination of 16-ary modulation and code rate of 10/15 [1]. Unlike uniform 16-ary Quadrature Amplitude Modulation (QAM), the number of candidates of in-phase or quadrature components is 8. In general, for *M*-ary 2 dimensional (2D)-NUC defined in ATSC 3.0, the number of all possible real-valued candidates in each dimension is *M*/2 [3] where *M* denotes the modulation order. Hence, several component bits of a given complex symbol in 2D-NUC are not separated into in-phase and quadrature components unlike uniform QAM.

III. PD-Based Decoding Scheme for ATSC 3.0 MIMO

The real-valued received signal vector for ATSC 3.0 MIMO system can be represented as follows [4]:

$$\begin{aligned}\mathbf{u}_i' &= \begin{bmatrix}\mathrm{Re}\{\mathbf{u}_i\}\\ \mathrm{Im}\{\mathbf{u}_i\}\end{bmatrix}\\ &= \begin{bmatrix}\mathrm{Re}\{\mathbf{H}\} & -\mathrm{Im}\{\mathbf{H}\}\\ \mathrm{Im}\{\mathbf{H}\} & \mathrm{Re}\{\mathbf{H}\}\end{bmatrix}\begin{bmatrix}\mathrm{Re}\{\mathbf{s}_i\}\\ \mathrm{Im}\{\mathbf{s}_i\}\end{bmatrix} + \begin{bmatrix}\mathrm{Re}\{\mathbf{N}_i\}\\ \mathrm{Im}\{\mathbf{N}_i\}\end{bmatrix}\\ &= \mathbf{H}' \cdot \mathbf{C} \cdot \mathbf{P} \cdot \mathbf{T} \cdot \mathbf{x}_i' + \mathbf{N}_i'\\ &= \mathbf{H}_e' \cdot \mathbf{x}_i' + \mathbf{N}_i'\end{aligned} \tag{2}$$

where $\mathbf{H}' = \begin{bmatrix}\mathrm{Re}\{\mathbf{H}\} & -\mathrm{Im}\{\mathbf{H}\}\\ \mathrm{Im}\{\mathbf{H}\} & \mathrm{Re}\{\mathbf{H}\}\end{bmatrix}$, $\mathbf{s}_i' = [\mathrm{Re}\{\mathbf{s}_i^T\} \quad \mathrm{Im}\{\mathbf{s}_i^T\}]^T$, and $\mathbf{N}_i' = [\mathrm{Re}\{\mathbf{N}_i^T\} \quad \mathrm{Im}\{\mathbf{N}_i^T\}]^T$. Here, $\mathrm{Re}\{\cdot\}$ and $\mathrm{Im}\{\cdot\}$ denote the real and imaginary parts, respectively. Additionally, the output of the MIMO precoder can be rewritten by using the real-valued input vector, $\mathbf{x}_i' = [\mathrm{Re}\{\mathbf{x}_i^T\} \quad \mathrm{Im}\{\mathbf{x}_i^T\}]^T$, of the MIMO precoder and the real-valued transformation matrices, $\mathbf{T}$, $\mathbf{P}$, and $\mathbf{C}$, for the stream combining, I/Q polarization interleaving, and phase hopping, respectively. Also, $\mathbf{H}_e' = \mathbf{H}' \cdot \mathbf{C} \cdot \mathbf{P} \cdot \mathbf{T}$ denotes the real-valued equivalent channel gain [4].

By using the real-valued signal representation for ATSC 3.0 MIMO, suboptimal decoding algorithms based on QR-decomposition can be considered. As mentioned in the previous section, several component bits of NUC in ATSC 3.0 cannot be separated into in-phase and quadrature parts and such bits are related across two layers, i.e., real and imaginary parts. Therefore, each inseparable bit has to be jointly considered with both of real and imaginary parts. However, uniform constellations were considered in previous works for real-valued channel models, this property of the NUC shape was not considered [7][8]. In this paper, a PD-based decoding scheme for ATSC 3.0 MIMO using NUCs is presented. The PD considers all possible transmitted symbols for the first layer which is the last element of the received vector [6]. Next, the cancellation for the second layer is performed for each possible candidate symbol. Note that the first layer means the last element of the real-valued received signal vector in reverse order. Similarly, all possible real-valued candidates for the first layer, i.e., the imaginary part of the second complex symbol, are considered in the proposed PD-based decoding for ATSC 3.0 MIMO. Note that the number of all possible real-valued candidates is *M*/2.

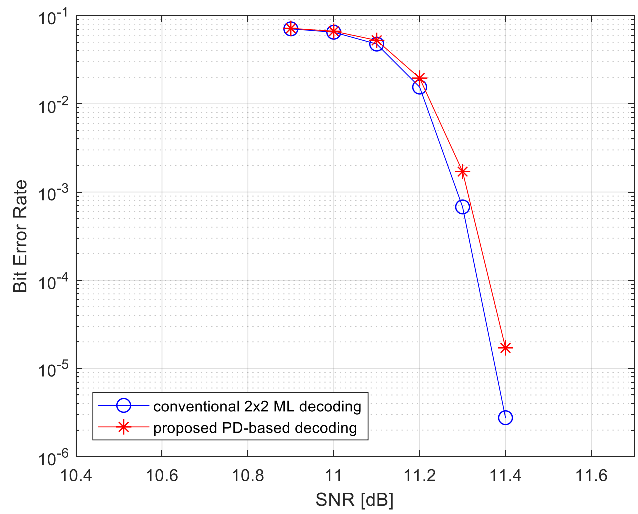

Fig. 2. The performance of ML decoding for 2x2 complex-valued channel model and proposed PD-based decoding scheme under AWGN channel

This paper assumes that the perfect dual-polarized antennas are used. Therefore, the in-phase component vector $[X_{2i,I} \quad X_{2i+1,I}]$ and the quadrature component vector $[X_{2i,Q} \quad X_{2i+1,Q}]$ in the real-valued signal vector can be decoupled for MIMO decoding. However, each real symbol $X_{2i,I}$ and $X_{2i+1,I}$ for in-phase components or each real symbol $X_{2i,Q}$ and $X_{2i+1,Q}$ for quadrature components cannot be decoupled. Hence, for the second layer, i.e., the imaginary part of the first complex symbol $X_{2i+1,Q}$, the cancellation for the symbol of the first layer has to be performed. However, for the third and fourth layers, i.e., $X_{2i,I}$ and $X_{2i+1,I}$, the cancellations for the symbols of the first and second layers are not performed.

On the other hand, inseparable bits for a complex symbol are related with both real and imaginary parts of the complex symbol. The first and third layers are related for 2*i*-th complex symbol and the second and fourth layers are related for (2*i*+1)-th complex symbol. For the separable bits, the hard decision for each candidate can be independently performed by computing Euclidean distance between the received signal for a given layer and each candidate symbol. For inseparable bits, on the other hand, the hard decision for each candidate is not performed in the first and second layers. Next, for the third layer, all candidates of the first layer are jointly used with all candidates of the third layer. Also, for the fourth layer, all candidates of the second layer are jointly used with all candidates of the fourth layer in a similar manner. After that, the Log-Likelihood Ratio (LLR) for each bit in a given complex symbol is calculated by using obtained candidate vectors.

Note that the complexity of the ML decoding is proportional to M^2. For the proposed PD-based decoding, on the other hand, the second layer can consider $(M/2)^2$

candidates. Next, the third and fourth layers can consider M and $M/2$ candidates, respectively. Therefore, the complexity of the proposed decoding is proportional to $(M/2)^2 + (3M/2)$ and it is lower than the complexity of the ML decoding.

IV. SIMULATION RESULT

Fig. 2 shows the performance of the ML decoding for 2x2 complex-valued channel model and proposed PD-based decoding scheme under AWGN channel. This paper assumes that the receiver perfectly knows the channel gain and uses the perfect dual-polarized antennas. Also, 16-ary NUC and code rate of 10/15 are used for the simulation. Due to the use of perfect dual-polarized antennas, the upper triangular matrix $\mathbf{R}$ by QR-decomposition of $\mathbf{H}_e^{'}$ becomes a diagonal matrix. Then, the interference cancellation at each layer can be negligible. The proposed decoding scheme shows a negligible performance loss compared with the ML decoding. Note that the complexity of the proposed PD-based decoding scheme with NUC is higher than the original PD scheme with uniform QAM due to the inseparable property of several bits in NUC.

V. CONCLUSION AND FUTURE WORK

In this paper, a suboptimal decoding scheme based on the QR-decomposition and PD for ATSC 3.0 MIMO system was proposed. In order to apply the concept of PD to ATSC 3.0 MIMO, the 4x4 real-valued channel model and the non-uniformly distributed shape of the constellation, i.e., NUC, in ATSC 3.0 were utilized. The complexity for the proposed decoding scheme can be reduced with a negligible performance loss compared with the ML decoding.

In the future work, more realistic channel models including multipath and time-varying channels should be considered to further analyze the performance and verify the availability of the proposed decoding scheme. Also, numerous sub-optimal decoders for MIMO decoding can be studied to compare the performance and complexity. Note that the inseparable property of NUCs should be considered for these further studies.

ACKNOWLEDGMENT

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Diffusion Recursive Least Square Adaptive Networks with Neighbor-Selection

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***Abstract*—Constrained communication resources and limited communication bandwidth are key issues for any task involving wireless sensor networks. This phenomenon motivated the authors to examine diffusion networks where only a fraction of neighbors participle in the communication process. In this context, we modify the Diffusion Recursive Least Square (DRLS) algorithm by allowing each node to receive intermediate estimates from a subset of its neighbors, called neighbor-selection DRLS. This results in significant reduction in communication overhead at the cost of some possible deterioration in the network performance. We derive a theoretical expression for the steady state Mean Square Deviation (MSD). Both numerical simulations and theoretical findings are used to validate the effectiveness of the proposed algorithm in providing a trade off between communication burden and estimation performance.**

Keywords–Adaptive network; diffusion; neighbor selection; recursive least-squares.

I. INTRODUCTION

Diffusion strategies are well-known techniques that enable real-time learning and collaboration in adaptive networks [1]–[3]. In these methods, information is gathered and processed at all agents in a simultaneous fashion. This results in a live sharing mechanism that ripples frequently through the whole network [4]. Consequently, significant improvements are accrued in estimation performance of each network agent, in comparison to the case in which nodes operate autonomously. Notable properties of such networks are scalability and robustness to node/link failures. Power and bandwidth resources, however, are the major constraints on performing a cooperative task in an adaptive network. Communication is constrained by the limited data transmission through radio links. Therefore, the attained advantages of diffusion strategies in terms of internode communications comes at an additional communication cost [5].

Following on the discussion in the previous paragraph, it is desirable to lower the level of internode communications as much as possible, while maintaining the benefits of cooperation. There are some existing efforts related to reducing the communication overheard, such as decreasing the dimension of the estimates [6]–[8], selecting a subset of the entries of the intermediate estimate vectors [9]–[12], and set membership filtering [13] [14]. In most earlier publications, it is assumed that the degree of each node is fixed and predefined by the network topology and, moreover, that every node senses data that is affected by information diffused by all of its neighbors. To the best of our knowledge, choosing a subset of neighboring nodes was considered in [5], [15]–[19], but only in diffusion least-mean-squares (LMS) networks. In this manuscript, we consider the case where only a subset of agents participate in the communication process. We focus on the scenario in [5], in which every node consults with only a subset of its neighbors and propose a novel reduced communication recursive least square algorithm, called neighbor selection DRLS. In this algorithm, which aims at further releasing the communication density of DRLS, each node updates its estimate and sends the intermediate estimate to only a subset of its neighbors. Moreover, the total amount of internode communication in the network is efficiently decreased with less performance degradation in comparison to the diffusion LMS algorithm. We derive a theoretical expression for the steady state MSD of the Neighbor Selection DRLS algorithm and verify its accuracy through numerical simulations.

The remainder of this paper is organized as follows: In Section II, we recall a conventional DRLS algorithm and formulate the proposed Neighbor Selection DRLS algorithm. The performance analysis is examined in Section III. We provide simulation results in Section IV and draw conclusions in Section V.

Notation: We use plain lowercase letters to denote scalars, lowercase bold letters to denote vectors and boldface uppercase letters for matrices.

II. ALGORITHM DESCRIPTION

A. *Conventional Diffusion RLS*

We consider a connected network of N nodes which aims to determine an unknown vector, $w^o \in \mathbb{R}^{M\times 1}$, in a distributed manner. At every time instant i and each node k, scalar measurements $d_{k,i} \in \mathbb{R}$ are related to regression vectors, $\mathbf{u}_{k,i} \in \mathbb{R}^{1\times M}$, via the following linear regression model [20]:

$$d_{k,i} = \boldsymbol{u}_{k,i}\mathbf{w}^o + v_{k,i} \tag{1}$$

where $v_{k,i}$ denotes the additive noise process. The vector $\mathbf{w}^o$ denotes the parameter of interest that the agents wish to identify.

We are then motivated to consider the following weighted least square problem:

$$\min_{w} \|\mathbf{y}_{k,i} - \mathbf{H}_{k,i}\boldsymbol{\psi}\|^2_{\Lambda_i} \tag{2}$$

where $\mathbf{y}_{k,i}$ and $\mathbf{H}_{k,i}$ are formed by stacking the history of measurement and noise samples of node k up to time i as follows:

$$\mathbf{y}_{k,i} = \operatorname{col}\{d_{k,i}, \ldots, d_{k,1}, d_{k,0}\} \tag{3}$$

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$$\mathbf{H}_{k,i} = \mathrm{col}\{\mathbf{u}_{k,i}, \ldots, \mathbf{u}_{k,1}, \mathbf{u}_{k,0}\} \tag{4}$$

where $\mathrm{col}\{\cdots\}$ denotes a column vector formed by stacking its arguments on top of each other. The solution $\boldsymbol{\psi}_{k,i}$ from (2) is given by [2]:

$$\boldsymbol{\psi}_{k,i} = \left(\mathbf{H}_{k,i}^T \boldsymbol{\Lambda}_i \mathbf{H}_{k,i}\right)^{-1} \left(\mathbf{H}_{k,i}^T \boldsymbol{\Lambda}_i \mathbf{y}_{k,i}\right) \tag{5}$$

where $\boldsymbol{\Lambda}_i \geq 0$ denotes a Hermitian weighting matrix. A common choice for $\boldsymbol{\Lambda}_i$ is

$$\boldsymbol{\Lambda}_i = \mathrm{diag}\left\{1, \lambda, \ldots, \lambda^i\right\} \tag{6}$$

$0 \ll \lambda \leq 1$ denotes an exponential forgetting factor whose value is usually close to unity. In this way, the closer the occurrence time of data is to present, the less heavily scaled it will be. Employing the recursive properties of

$$\mathbf{H}_{k,i}^T \boldsymbol{\Lambda}_i \mathbf{H}_{k,i} = \lambda \mathbf{H}_{k,i-1}^T \boldsymbol{\Lambda}_{i-1} \mathbf{H}_{k,i-1} + \mathbf{u}_{k,i}^T \mathbf{u}_{k,i} \tag{7}$$

$$\mathbf{H}_{k,i}^T \boldsymbol{\Lambda}_i \mathbf{y}_{k,i} = \lambda \mathbf{H}_{k,i-1}^T \boldsymbol{\Lambda}_{i-1} \mathbf{y}_{k,i-1} + \mathbf{u}_{k,i}^T d_{k,i} \tag{8}$$

alongside defining $\mathbf{P}_{k,i} = \left(\mathbf{H}_{k,i}^T \boldsymbol{\Lambda}_i \mathbf{H}_{k,i}\right)^{-1}$, and as well making use of the so-called matrix inversion formula [21], called Sherman-Morrison Formula, to (7), the following recursive equations to assess $\boldsymbol{\psi}_{k,i}$ are given:

$$\mathbf{P}_{k,i} = \lambda^{-1} \left(\mathbf{P}_{k,i-1} - \frac{\lambda^{-1} \mathbf{P}_{k,i-1} \mathbf{u}_{k,i}^T \mathbf{u}_{k,i} \mathbf{P}_{k,i-1}}{1 + \lambda^{-1} \mathbf{u}_{k,i} \mathbf{P}_{k,i-1} \mathbf{u}_{k,i}^T} \right) \tag{9}$$

$$\boldsymbol{\psi}_{k,i} = \boldsymbol{\psi}_{k,i-1} + \mathbf{P}_{k,i} \mathbf{u}_{k,i}^T \left(d_{k,i} - \mathbf{u}_{k,i} \boldsymbol{\psi}_{k,i-1}\right) \tag{10}$$

Due to the fact that the intermediate value $\boldsymbol{w}_{k,i}$ at node k is generally a better estimate for $\mathbf{w}^o$ than $\boldsymbol{\psi}_{k,i}$, we replace $\boldsymbol{\psi}_{k,i-1}$ by $\mathbf{w}_{k,i-1}$ in (10)

$$\boldsymbol{\psi}_{k,i} = \mathbf{w}_{k,i-1} + \mathbf{P}_{k,i} \mathbf{u}_{k,i}^T \left(d_{k,i} - \mathbf{u}_{k,i} \mathbf{w}_{k,i-1}\right) \tag{11}$$

It is common that the local estimates are scattered outside of each node's own neighborhood. Then, the diffusion RLS strategy comprises two stages: adaptation and aggregation.

1) *Adaptation:* Each node estimator is updated utilizing observed data $\{d_{k,i}, \mathbf{u}_{k,i}\}$ in (9) and (11). The resulting pre-estimates are called $\boldsymbol{\psi}_{k,i}$ as in (12).
2) *Aggregation:* Each node diffuses its local pre-estimate with its neighbors, collects the estimators from its neighbors and performs a weighted average as

$$\mathbf{w}_{k,i} = \sum_{l \in \mathcal{N}'_k} c_{lk} \boldsymbol{\psi}_{l,i} \tag{12}$$

to obtain the estimate $\mathbf{w}_{k,i}$ (via so-called spatial update). Where $\mathcal{N}'_k$ denotes the close neighborhood of node k, i.e., it consists of a set of all nodes communicating to node k, including k itself. The coefficients c_{lk} are designed to satisfy the following condition:

$$C^T \mathbb{1}_N = \mathbb{1}_N \tag{13}$$

where the notation $\mathbb{1}$ denotes an $N \times 1$ column vector with all one entries. To minimize the communication density, here, we cover the diffusion RLS strategy, which does not involve any information exchange.

B. Neighbor-Seletion Diffusion RLS

The aggregation step (12) improves the estimation performance. However, this is compromised by the communication density. In order to reduce the amount of communication, we consider the case in which each node is allowed to diffuse the update estimate with only a subset of its neighborhood $\mathcal{N}_k$ [5]. Generally speaking, because a subset of the information is available at node k to perform (12), the aggregation phase would be updated so that it could be performed with current available information. Doing so, we can decrease the internode communications that is being accomplished among nodes and establish a trade-off between estimation performance and communication cost.

Let $\delta_k = |\mathcal{N}_k|$ be the degree or valency of node k, where $|\cdot|$ is the cardinality operator. To achieve this, assume node k communicates at each time instant i to receive the intermediate estimate, $\boldsymbol{\psi}_{l,i}$, from $0 < n_k \leq \delta_k$. To-be-selected neighboring nodes of node k at iteration i are characterized by a neighborhood-selection variable as $a_{kl,i}$. This variable determines the status of the link, being active or inactive, between node k and l at time instant i.

The neighbor-selection variable is defined as follows:

$$a_{lk,i} = \begin{cases} 1 & \text{if } l \in \mathcal{N}_{k,i}^D \\ 0 & \text{otherwise} \end{cases} \tag{14}$$

where $\mathcal{N}_{k,i}^D$ is the neighborhood of node k at time instant i and consists of all the nodes, which transmit their intermediate estimates to node k. Adjusting $a_{kl,i} = 1$ means that node k communicates with its neighboring node l at iteration i and receives its intermediate estimate to employ at the aggregation step. Having, $a_{lk,i} = 0$ means that node k does not receive the intermediate estimate of its neighbor l at iteration i.

With regards to the proposed neighbor selection scheme, the following remark is made [5]:

Remark 1. *The neighbor-selection variable $\{a_{lk,i}\}$ is mutually independent of each element of set $\{\mathbf{u}_{k,i}, d_k(i), v_k(i)\}$. Moreover, the neighbor-selection probability, denoted by ρ_k is shift-invariant and identical for all the neighbors. This probability is expressed as:*

$$\rho_k = \mathbb{E}\left[a_{lk,i}\right] = \frac{n_k}{d_k}$$

When the intermediate estimates of only n_k neighbors are received at node k, we instead propose a new aggregation method that uses the node's own intermediate estimate as a proxy [19] for missing data and changes (3):

$$\mathbf{w}_{k,i} = c_{kk} \boldsymbol{\psi}_{k,i} + \sum_{l \in \mathcal{N}_k} c_{lk} [a_{lk,i} \boldsymbol{\psi}_{l,i} + (1 - a_{lk,i}) \boldsymbol{\psi}_{k,i}] \tag{15}$$

Accordingly, the considered neighbor-selection diffusion RLS algorithm utilizes (9) and (11) in the adaptation phase and (15) for the aggregation phase. It is noteworthy to say that (3) and (15) have the same computational complexity. Consequently, the considered algorithm, i.e., (9), (11), and (15), requires the same number of arithmetic operations as the diffusion RLS algorithm.

III. Performance Analysis

To proceed with the analysis, we make the following assumptions:

Assumption:

1) The regression data $\mathbf{u}_{k,i}$ are temporally white and spatially independent random variables with zero mean and covariance matrix $\mathbf{R}_{u,k} \triangleq \mathbb{E}\left[\mathbf{u}_{k,i}^T \mathbf{u}_{k,i}\right] \geq 0$.
2) The noise signal $v_{k,i}$ is temporally white and spatially independent random variable with zero mean and variance $\sigma_{v,k}^2$.
3) The regression data $\{\mathbf{u}_{m,i_1}\}$, and the model noise signals v_{n,i_2}, are mutually independent random variables for all indexes $\{i_1, i_2, m, n\}$.
4) For sufficiently large i, at any node k, we can replace $\mathbf{P}_{k,i}$ and $\mathbf{P}_{k,i}^{-1}$ with their expected values, $\mathbb{E}\left[\mathbf{P}_{k,i}\right]$ and $\mathbb{E}\left[\mathbf{P}_{k,i}^{-1}\right]$, respectively.
5) For a sufficiently large i, at any node k, we have $\mathbb{E}\left[\mathbf{P}_{k,i}\right] = \mathbb{E}\left[\mathbf{P}_{k,i}^{-1}\right]^{-1}$

A. Network update equation

Define $M \times 1$ error vector as follows:

$$\tilde{\boldsymbol{\psi}}_{k,i} \triangleq \mathbf{w}^o - \boldsymbol{\psi}_{k,i} \tag{16}$$

$$\tilde{\mathbf{w}}_{k,i} \triangleq \mathbf{w}^o - \mathbf{w}_{k,i} \tag{17}$$

$$\tilde{\mathbf{w}}_i \triangleq \mathrm{col}\left\{\tilde{\mathbf{w}}_{1,i}, \ldots, \tilde{\mathbf{w}}_{N,i}\right\} \tag{18}$$

Using the data model in (1) and subtracting $\mathbf{w}^o$ from both sides of the relation in (11), we get

$$\tilde{\boldsymbol{\psi}}_{k,i} = \tilde{\mathbf{w}}_{k,i-1} - \mathbf{P}_{k,i}\mathbf{u}_{k,i}^T\left[\mathbf{u}_{k,i}\tilde{\mathbf{w}}_{k,i-1} + v_{k,i}\right] \tag{19}$$

Using the same procedure as stated in [12], the equation above can be written in the following form:

$$\tilde{\boldsymbol{\psi}}_{k,i} = \lambda\tilde{\mathbf{w}}_{k,i} - (1-\lambda)\,\mathbf{R}_{u,k}^{-1}\mathbf{u}_{k,i}^T v_{k,i} \tag{20}$$

Moreover, subtracting both sides of (20) from w^o gives

$$\tilde{\mathbf{w}}_{k,i} = \left(1 - \sum_{l\in\mathcal{N}_k} a_{lk,i}c_{lk}\right)\tilde{\boldsymbol{\psi}}_{k,i} + \sum_{l\in\mathcal{N}_k} a_{lk,i}c_{lk}\tilde{\boldsymbol{\psi}}_{l,i} \tag{21}$$

which leads to

$$\tilde{\mathbf{w}}_i = \lambda\mathfrak{B}_i\tilde{\mathbf{w}}_{i-1} - \mathfrak{B}_i\mathbf{\Pi}\mathbf{s}_i \tag{22}$$

where

$$\mathbf{\Pi} \triangleq (1-\lambda)\,\mathrm{diag}\left\{\boldsymbol{R}_{u,1}^{-1}, \ldots, \boldsymbol{R}_{u,N}^{-1}\right\} \tag{23}$$

$$\boldsymbol{s}_i \triangleq \left\{\mathbf{u}_{1,i}^T v_{1,i}, \ldots, \mathbf{u}_{N,i}^T v_{N,i}\right\} \tag{24}$$

$$\mathfrak{B}_i = \boldsymbol{\mathcal{B}}_i \otimes \mathbf{I}_M \tag{25}$$

$$\boldsymbol{\mathcal{B}}_i = \begin{bmatrix} \mathbf{B}_{11,i} & \cdots & \mathbf{B}_{1N,i} \\ \vdots & \ddots & \vdots \\ \mathbf{B}_{N1,i} & \cdots & \mathbf{B}_{NN,i} \end{bmatrix} \tag{26}$$

where

$$\mathbf{B}_{p,q,i} = \begin{cases} 1 - \sum_{l\in\mathcal{N}_p} a_{pl,i}c_{pl} & \text{if } q = p \\ a_{pq,i}c_{pq} & \text{if } q \in \mathcal{N}_p \\ 0 & \text{otherwise} \end{cases} \tag{27}$$

and $\otimes$ denotes the Kronecker product.

For any arbitrary symmetric nonnegative-definite matrix $\mathbf{\Sigma}$, using the alternative notation $\|\mathbf{x}\|_{\boldsymbol{\sigma}}^2$, where $\boldsymbol{\sigma} = \mathrm{vec}\left\{\mathbf{\Sigma}\right\}$, to refer to the weighted square quantity $\mathbf{x}^T\Sigma\mathbf{x}$ and following similar arguments to those in [3], we arrive at the following variance relation:

$$\mathbb{E}\left[\|\tilde{\mathbf{w}}_i\|_{\boldsymbol{\sigma}}^2\right] = \mathbb{E}\left[\|\tilde{\mathbf{w}}_{i-1}\|_{\lambda^2\mathbf{\Phi}\boldsymbol{\sigma}}^2\right] + \mathrm{vec}^T\left\{\boldsymbol{\mathcal{G}}\right\}\mathbf{\Phi}\boldsymbol{\sigma} \tag{28}$$

where

$$\boldsymbol{\mathcal{G}} = \mathbf{\Pi}\mathbb{E}\left[\mathbf{s}_i\mathbf{s}_i^T\right]\mathbf{\Pi} \tag{29}$$

which, in view of the *Assumptions*, can be expressed as

$$\boldsymbol{\mathcal{G}} = (1-\lambda)^2\left\{\sigma_{v,1}^2\mathbf{R}_{u,1}^{-1}, \ldots, \sigma_{v,N}^2\mathbf{R}_{u,N}^{-1}\right\} \tag{30}$$

and

$$\mathbf{\Phi} = \mathbb{E}\left[\mathfrak{B}_i^T \otimes \mathfrak{B}_i^T\right] \tag{31}$$

We arrive at the following expression for the network MSD (η)

$$\eta = \frac{1}{N}\mathrm{vec}^T\left\{\boldsymbol{\mathcal{G}}\right\}\mathbf{\Phi}\left(\mathbf{I}_{M^2N^2} - \lambda^2\mathbf{\Phi}\right)^{-1}\mathrm{vec}\left\{I_{MN}\right\} \tag{32}$$

We consider an adaptive network with $N = 20$ nodes. Each node has between one and seven neighbors excluding itself. We assume that each node, on average, is connected to four other agents. The regressors, $\mathbf{u}_{k,i}$, were chosen Gaussian i.i.d with randomly generated different diagonal covariance matrices, $\mathbf{R}_{u,k}$. The additive noise signals at nodes are zero mean Gaussian with variances $\sigma_{v,k}^2$ and independent of the regression data. The traces of the covariance matrix regressors and the noise variances at all nodes, $\mathrm{tr}\left\{\mathbf{R}_{u,k}\right\}$ and $\sigma_{v,k}^2$, are shown in Fig. 1. It is noteworthy that we obtain the network MSD learning curves of all figures by averaging over 50 experiments and the unknown parameter $\mathbf{w}^o$ of length $M = 8$ is randomly generated. In the proposed algorithm, we determine the number of neighbors with which each node communicates at each iteration to receive their intermediate estimates via $n_k = \min(K, \delta_k)$ where $0 \leq K \in \mathbb{N} < \delta_k$ specifies the maximum number of consulted neighbors of every node at each iteration. We use the relative-degree weights for $\{c_{lk}\}$ in the combination phase. In Fig. 2, we simulate the learning curves of instantaneous network MSD for different values of K. Fig. 3 also demonstrates the steady-state MSD of all the nodes for different values of K when $\lambda = 0.99$.

IV. Conclusion and Future Work

We introduced a neighbor-selection DRLS for distributed adaptive estimation. This algorithm provides reduced internode communication and bandwidth usage by allowing each node to receive intermediate estimates from a fraction of its neighbors. We derive an expression for the network MSD. The simulation results conform with the theoretical derivations. They illustrate that a trade off between communication cost and estimation performance can be obtained. In our future work we plan to derive the optimum combination weights that minimize the steady-state MSD at every node.

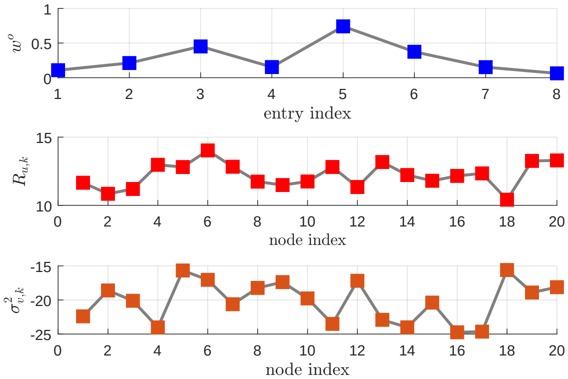

Figure 1. Entries of $\mathbf{w}^o$, tr $\left\{\mathbf{R}_{u,k}\right\}$, and $\left\{\sigma^2_{v,k}\right\}$ used in simulation.

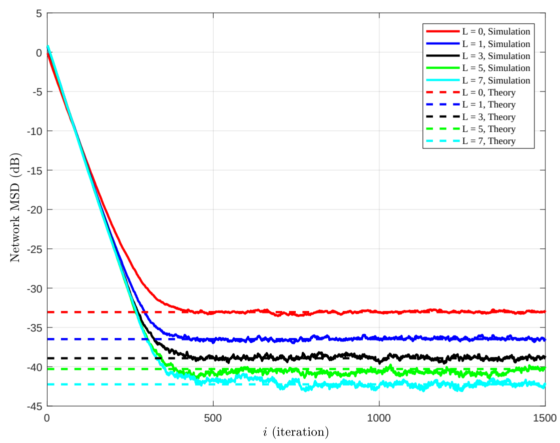

Figure 2. Experimental and thoretical network MSD curves of the neighbor-selection DRLS algorithm with different values K of when $\lambda = 0.95$.

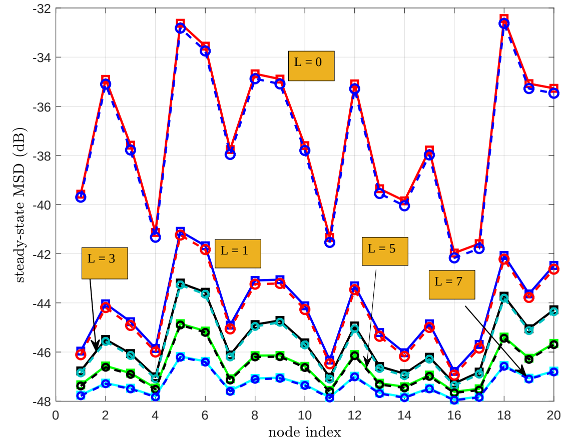

Figure 3. Theoretical and experimental steady-state MSDs of the neighbor-selection DRLS algorithm at each node for different values of K when $\lambda = 0.99$.

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Utilizing the Maximum Spanning Tree to Construct Stability-based Routes in Self-driving Vehicular Networks

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***Abstract*—In vehicular ad hoc networks (VANETs), the communication is challenging due to fast topology changes, frequent route disruptions and recoveries, and the highly variable traffic density caused by the vehicles' mobility. The stability of routes between source vehicles and destination vehicles becomes an important issue. It can be expected that most of the vehicles will be self-driving cars in the future. The most important characteristic of the self-driving vehicular environment is that accurate future positions of vehicles can be obtained. By utilizing the predicted trajectories of self-driving vehicles, the Link Expiration Time (LET) and the Route Expiration Time (RET) can be estimated. The most stable forwarding route, which has the longest RET, can be constructed between source vehicles and destination vehicles. However, the time complexity of determining the most stable path grows drastically with the increase of the vehicle density. In this paper, by utilizing maximum spanning trees (MST), an MST-based route construction scheme with predicted trajectories is developed. The simulation results demonstrate that the calculation efficiency of the scheme is better than the PTSRC scheme especially in the environment with the higher vehicle densities.**

Keywords–self-driving; vehicular network; stable routing; maximum spanning tree.

I. Introduction

A vehicular ad hoc network (VANET) [1] is a specific application for the wireless communication technology implementation in Intelligent Transportation System (ITS) [2]. Due to the Dedicated Short Range Communications (DSRC) standardization, a vehicle can communicate with either a vehicle (V2V) or a road side unit (V2R). Unlike typical MANETs [3], the VANET changes its topology frequently. Network disconnections could happen because nodes have higher mobility, so it is more difficult to maintain stable connections between vehicles for delivering messages.

A self-driving car, also known as an autonomous driving car, a driverless car, or a robotic car, is a vehicle that can drive by itself without a human driver. Many companies, including Google, Apple, Tesla, and Intel, are actively developing self-driving cars. The distinguished members of the IEEE announced that they selected self-driving vehicles as the most promising form of ITS, and expected that autonomous cars would account for up to 75% of vehicles on the roads by 2040 [4]. Each vehicle will have its own designated lane, and the gaps between vehicles will be shortened. Stop signs and traffic lights may be no longer needed. Consequently, vehicles can move faster and traffic jams can be minimized. In addition, with the help of electronic blind spot assistance, automated emergency braking systems, the adaptive cruise control, and the lane departure warning, driving will be much safer because computers would react rapidly to avoid accidents.

Due to the development trend of self-driving cars, it is envisioned that most vehicles in the road networks will be self-driving cars controlled by the cloud system and equipped with wireless communication devices [5][6]. Therefore, the concept of Self-Driving Vehicular Networking Technology was described by the authors. The trajectories (the planned moving path of self-driving vehicles) are collected and sent to the cloud system. By utilizing the trajectories, the travel time of each vehicle in each road segment can be estimated. During the travel of each vehicle, if the current position deviates too much from the predicted position, the vehicle will communicate with the server to update its information. The 3G/4G cellular technologies for transmitting packets bring some advantages, such as the larger transmission range. However, it may encounter some problems [7]. For example, the cost of cellular communications is relatively high, and its bandwidth is shared by all users within the cell. Therefore, it is reasonable to deliver data with the DSRC technologies.

In self-driving vehicular networks, if the accurate trajectory information is available, the ad-hoc multi-hop data delivery can be enhanced. A scheme that utilizes predicted trajectories for stability-based route construction (PTSRC) was developed [8]. The PTSRC analyzes the trajectory information for each self-driving vehicle to predict future distances between vehicles, so the Link Expiration Time (LET) and the Route Expiration Time (RET) can be calculated. The PTSRC scheme needs to search for all the available paths, and it could increase its computation time dramatically.

In this paper, an MST-based PTSRC scheme is designed to reduce the time complexity of the PTSRC. With the characteristics of the maximum spanning tree, it is no longer necessary to examine all the paths to determine the most stable path.

The remainder of the paper is organized as follows. Motivations of this work are described in Section II, related work is surveyed in Section III, the system model is described in Section IV, the protocol is described in Section V and its performance is analyzed in Section VI. This paper is concluded in Section VII.

II. Motivation

The shortest path routing protocols in the MANETs, such as DSR [9] and AODV [10], are not suitable in the VANETs. In the VANETs, transmission routes are easier to be disconnected due to the fast and frequent movement of the vehicles.

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Recent researches have unveiled that a critical factor for the routing performance in VANETs is the lifetime of routes. If the lifetime of the established route is short, the route has to reconstruct frequently. The new route may fail instantly after the establishment, resulting in a series of successive route reconstructions. The failure of a link is sufficient to render an established route failed, and the failure invalidates all the routes containing this link. Several route reconstructions will be necessary simultaneously, introducing the corresponding overhead and causing extend delivery delay [11].

In self-driving vehicular networks, the most important characteristic is that the prediction for future position of vehicles could be sufficiently accurate. In order to calculate the most stable routes, the server has to calculate all possible paths first [8]. It takes a serious computational load. Furthermore, the most stable route which has been calculated can not be effectively used by other connections. Fortunately, before finding the most stable route, some links are not necessary to be considered because the smallest lifetime link in a circle must be replaced by a larger lifetime route. With this observation, a MST-based PTSRC scheme is presented in this paper.

III. Related Work

Some researchers derive the expected lifetimes based on the information of nodes' positions and velocities [12][13]. On the other hand, some researchers measure the link quality using its signal strength [14][15]. Furthermore, Panwar et al. proposed that the route stability was the combination of LET and the stability factor [16]. The LET is calculated based on relative distance and relative velocity. The stability factor is the quality. Sofra et al. proposed a cross-layer approach which utilized physical layer information and predicted the remaining lifetime of a link [17].

A dynamic vehicle navigation protocol, called STN, searches for the most time-efficient paths for self-driving vehicles [5]. The STN utilizes trajectories to predict the future traffic conditions, and then the travel time of each vehicle on several candidate paths to the destinations is calculated by the central server. By evaluating the possible paths, the most time-efficient path can be determined. In the TFNP scheme, the trajectory information of self-driving vehicles is used to predict future encounter events and to schedule data transmissions [6].

In the PTSRC scheme [8], when a source vehicle transmits packets to a destination vehicle, the server will analyze the current network graph and calculate the LET of each link. All the paths have to be found out and the corresponding RETs are calculated. The maximum RET path is the most stable route. The PTSRC may encounter a computation issue. When the network is close to a fully connected graph, the time complexity of finding all paths will approach to $\Omega(n!)$ according to the permutation of nodes.

IV. System Model

A. Assumptions

It is assumed that all vehicles participating in the system are fully self-driving vehicles with wireless communication capability through a short-range wireless channel, such as using WAVE/DSRC technology [18]. A vehicle knows its location through a GPS device, and learns the road topology by a digital map.

The central server has digital maps with fundamental characteristics such as road length, road width, and speed limits. It has sufficient computation capability and storage space as well. It is assumed that the central server has accurate trajectory information on every vehicle. The trajectory information consists of coordinates and timestamp per second. More precisely, the server knows the predicted positions of each vehicle in the future.

The trajectory information stored in the server is assumed to be perfect. In real life, however, there may be some deviation in prediction due to some accidental events such as pedestrians crossing some streets or unpredictable car accidents. As the first attempt to study routes construction in self-driving vehicular environments, the proposed scheme does not handle this issue. The problems caused by the time deviation in trajectory information is a part of future work.

B. Scenario

When a vehicle starts traveling, it first sends a request to the server through the 3G or 4G mobile communication technologies. After receiving the request from a vehicle, the server plans a driving path for the vehicle, according to the current traffic conditions by navigation protocols such as STN [5]. With all trajectories of self-driving vehicles, the server calculates the future positions of each vehicle and the corresponding timestamp. The positions and corresponding time information (call "trajectory information") are stored in the server. The server then utilizes the trajectory information of all vehicles to construct the most stable route and the alternative routes (which will be used prior to route-breakage) for the requesting vehicle, and the forwarding routes are sent back to the requesting vehicle via 3G/4G mobile communication technologies.

During the travel, each vehicle may communicate with the central server through 3G/4G cellular technologies to keep its information at server up-to-date. When the vehicles need to communicate with each other, they basically use Dedicated Short Range Communication (DSRC) technologies and forward messages hop by hop to the destination. Each vehicle can also communicate with the server periodically to ask the server to provide the updated forwarding routes to a certain packet destination.

V. Protocol Description

The MST-based PTSRC scheme first analyzes the trajectory information for all self-driving vehicles in the road network to estimate the future positions of vehicles. The distance between vehicles and their neighbors can be acquired based on trajectory information. Then, the LET and RET are estimated to construct the stable routes. When a self-driving vehicle has to communicate with other vehicles for a long time, the stable routes can be captured from the server through 3G/4G cellular technologies.

A. Estimation of LET and RET

The LET is the lifetime of links and The RET is the lifetime of routes. It is assumed that the transmission is not affected by any obstructions. Thus, the distance between two cars could be used to estimate their LET.

A vehicle's neighbors are defined as the set of the other vehicles in its transmission range TR. It is assumed that the

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trajectory information is stored in the server [8]. The trajectory information consists of the coordinates and timestamps. With the accurate trajectory information, the future positions of self-driving vehicles can be estimated and the distance between vehicles can be calculated.

The server calculates the distance between vehicles by the vehicles' coordinates that are in trajectory information. Let two vehicles V_i and V_j with coordinates (x_i, y_i) and (x_j, y_j). The distance D_{ij} between vehicles V_i and V_j can be estimated by:

$$D_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{1}$$

By utilizing the self-driving car environment and the trajectory information for all vehicles, the LET of two neighbors can be calculated by the server. The $LET_{ij}^{t_0}$ between vehicles V_i and V_j at time t_0 can be estimated by

$$LET_{ij}^{t_0} = \begin{cases} t_1 - t_0, & D_{ij}^{t_0} \leq TR \\ 0, & D_{ij}^{t_0} > TR \end{cases} \tag{2}$$

where

$$t_1 = max\left\{t' | \forall t \in [t_0, t'], D_{ij}^{t} \leq TR\right\}$$

The neighbor and LET information is stored in the server, as shown in Figure 1.

Vehicle ID	Timestamp	Neighbor ID	LET
A	1:32	B	6
A	1:32	C	4
A	1:32	D	5

Figure 1. Neighbor and LET information format.

After estimating the LET of links, the server can determine the RET of the route by the minimum LET along the route. A single link of a route is disconnected, the entire route will be disconnected. If there exists a route R_{n-1} that consists $n-1$ links $l_{01}, l_{12}, l_{23}, ..., l_{(n-2)(n-1)}$ between n vehicles such as $0, 1, ..., n-1$. The RET can be calculated as Equation 3.

$$RET = min\left\{LET_{ij}\right\}, \quad \begin{array}{l} i = 0, ..., n-2 \\ j = i+1 \end{array} \tag{3}$$

B. Stability-based Route Construction

1) Concept: The basic idea of the stability-based route construction algorithm is to analyze the RET of routes which are between source vehicles and destination vehicles. If the LET along each hop on the route can be estimated, the RET of the route will be able to be estimated. To explain the idea, consider the example illustrated in Figure 2.

Vehicle V_1 has to send packets to V_6, it sends a start-up request to central server via cellular technologies. After planning the driving path for V_1, the server is able to construct the most stable route form V_1 to V_6. Before this, V_2, V_3, V_4, and V_5 have requested the server to plan paths and start their travels. The server has the trajectory information of these vehicles. As illustrated in Figure 2, there are two routes between V_1 and V_6. One contains route (V_1, V_2, V_3, V_5, V_6) with LET (4, 4, 3, 6), and the other route (V_1, V_2, V_4, V_5, V_6) with LET (4, 5, 4, 6). Since RET is the minimum LET for the route. The server can estimate the RET of both routes. In this example, route (V_1, V_2, V_4, V_5, V_6) is more stable since it will expire after four seconds, therefore it is chosen as the route to forward packets.

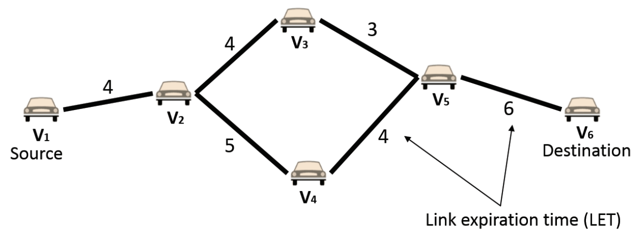

Figure 2. Routes between source and destination.

2) MST-based PTSRC Algorithm: In the PTSRC, in order to search for the maximum RET routes, the server must find all possible routes and calculate the RET of each route. However, in high traffic density, the time complexity of calculating all routes is quite high. In particular, when the network is close to the fully connected graph, the time complexity of finding all paths will be $\Omega(n!)$ according to the permutation of nodes. In order to solve this problem, the maximum spanning tree (MST) is utilized to reduce the time complexity in this paper. An MST is a spanning tree whose weight is greater than or equal to the weight of every other spanning tree.

Theorem 1. *Given a connected network $G = (V, E)$, V is the set of vehicles, E is the set of links and the weight is LET. If $(V_1, V_2) \in V^2$, then the RET of the route on an MST of G is the maximum RET between V_1 and V_2.*

Proof Theorem 1 can be proved by contradiction. Let S_X be the route of V_S and V_D on an MST that the corresponding RET is R_X and consists n links $x_0, x_1, ..., x_{n-1}$. Assume that there is another route S_Y whose corresponding RET is R_Y such that $R_X < R_Y$ and consists m links $y_0, y_1, ..., y_{m-1}$. Obviously, S_X and S_Y will form a cycle C. Since (3), $min\{x_i | i = 0, 1, ..., n-1\} < min\{y_j | j = 0, 1, ..., m-1\}$. Thus, the minimum edge e is on S_X and belongs to an MST. According to cycle property [19], for any cycle C in the graph, if the weight of an edge e is smaller than the individual weights of all other edges of C, this edge cannot belong to an MST. Therefore, the assumption does not hold. The Theorem 1 is proved.

In this paper, the server builds an MST by basic Kruskal algorithm which takes $O(e\ log\ e)$ time [20]. According to the Theorem 1, the largest RET can be found in linear time if the corresponding MST has been build. Note that an MST could be utilized by any pair of source node and destination node. For an example shown in Figure 3, according to the MST, the maximum RET from V_S to V_D is 7, and the maximum RET from V_1 to V_5 is 9, and so on. Especially in the case that the

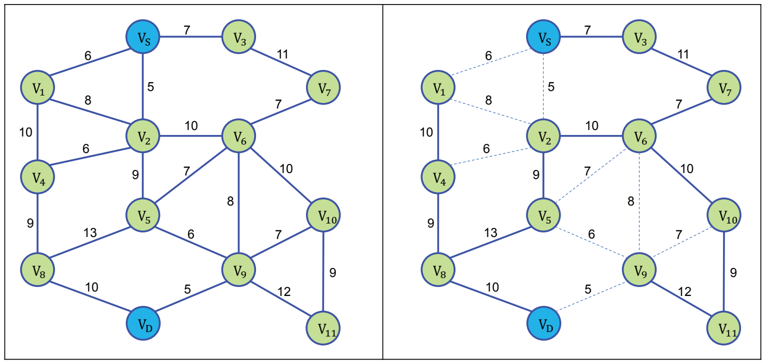

Figure 3. A route on a maximum spanning tree.

connection request is frequent, utilizing a corresponding MST has been established could reduce lots of computation time.

The route on a maximum spanning tree is not always the optimal solution. For an example shown in Figure 3, the route (V_S, V_3, V_7, V_6, V_2, V_5, V_8, V_D) is on an MST and it takes 7 hops. However, the another route (V_S, V_3, V_7, V_6, V_5, V_8, V_D) takes less hops and the RET is the same. There are two advantages to choose a route with less hops. First, the less-hop transmissions can reduce the transmission failure rate in real environment. Second, if all the vehicles transport packets through the routes on the maximum spanning tree, the load will increase. In contrast, selecting a route that is not on an MST contributes to load balancing.

To find the most stable route which has the minimum hops, breadth-first search(BFS) [21] which takes $O(e)$ time is utilized. After the maximum RET_{max} having been calculated, the server eliminates all edges that are smaller than RET_{max} to create a sub-graph G'. Thus, the only route from V_S to V_D on G' is the most stable route. Then, on G', the server executes BFS at V_S until V_D is searched. According to the characteristics of BFS, a BFS tree is a shortest-path tree in an unweighted graph. In other words, a BFS tree is a minimum-hop tree in VANETs. Thus, the route obtained by BFS has the minimum hops. The most stable route which has the minimum hops is found.

3) Short Required Connection Time: Furthermore, if a request needs short connection time, it may not be necessary to find the most stable route. In Figure 3, if the required connection time between V_S and V_D is 3, it is clear that there is no need to build an MST to find the most stable route. All the server needs to do is find the minimum-hop route (V_S, V_2, V_5, V_8, V_D).

When there is a connection request between V_S and V_D, the server builds a subgraph SbR by edges whose LET is greater than or equal to the required connection time. If there are routes between V_S and V_D on SbR, the server executes BFS to find the minimum-hop route. If not, the server searches for the most stable routes according to corresponding MST and then select the minimum-hop one. The algorithm is shown in Algorithm 1.

Algorithm 1 Algorithm of MST-based Stability Route Construction.

Definition:
V_i: The set of all autonomous vehicles in the road network.
N^i: The set of neighbors of an autonomous vehicle V_i.
LET_{ij}: The LET of the link between a vehicle V_i and a neighbor N^i_j.
R_{SD}: The routes from V_S to V_D.
T_{SD}: The required connection time between V_S and V_D.
Algorithm:
if V_S and V_D are on the same connected network G. **then**
  for all $LET_{ij} \geq T_{SD}$. **do**
    Insert (N^i_j, LET_{ij}) into sub-graph SbR.
  end for
  if $\exists SbR \in R_{SD}$. **then**
    Find the minimum-hop route by doing breadth-first search on SbR.
  else
    if A corresponding MST on G has not been build. **then**
      Build a corresponding MST on G by Kruskal algorithm.
    end if
    Calculate RET_{max} of the route on the MST.
    for all $LET_{ij} \geq RET_{max}$. **do**
      Insert (N^i_j, LET_{ij}) into sub-graph G'.
    end for
    if The number of $RET_{max} > 1$. **then**
      Find the most stable route which has the minimum hops by doing breadth-first search on G'.
    end if
  end if
end if

VI. PERFORMANCE EVALUATION

This section describes the simulation environment, the protocol for comparison, and the evaluation results.

A. Simulation Environment Setup

EstiNet 9.0 network simulator and emulator [22], formerly known as NCTUns (National Chiao Tung University Network Simulation) [23], is used for the simulation of MST-based PTSRC. The simulator integrates traffic simulation capabilities, such as road network construction and vehicle mobility control. It also supports the simulation of IEEE 802.11(p)/1609 WAVE wireless vehicular networks.

The simulation environment is a 2.0 km $\times$ 2.0 km grid

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road network with 49 intersections. Each road has two lanes per direction, and the width of lane is 20 m. The speed limit is 11 m/s. Packets are generated from randomly selected vehicles, and the destination vehicles are also randomly selected. There are roughly 800 connection requests during the simulation (2 requests per second on average during the first 400 seconds of the simulation). The packets lifetime is 600 seconds. The size of data packets is 512 bytes. The simulation parameters are listed in Table I.

TABLE I. SIMULATION PARAMETERS.

Parameter	Value
Processor	Intel(R) Core(TM) i7-3820 CPU
Installed memory(RAM)	16.0GB
System type	64-bit Operating System
Simulation area	$2.0 \times 2.0\ km^2$
Simulation time	1000 s
Speed limit	11 m/s
Number of lanes	2 lanes per direction
Radio range of vehicles	250 m
Packet size	512 Bytes

B. Compared Protocol

Our protocol is compared with the PTSRC [8] whose details are described in Algorithm 2. In PTSRC scheme, if there is a route between a source vehicle and a destination vehicle, the server will search for all the routes and select the most stable route with the minimum number of hops. For fair comparison, if their most stable routes have the same minimum number of the hops, the MST-based PTSRC and the PTSRC will use the same route. Each algorithm is executed 100 times in the simulation.

Algorithm 2 Algorithm of Stability-based Route construction.

Definition:
- V_i: The set of all autonomous vehicles in the road network.
- N^i: The set of neighbors of an autonomous vehicle V_i.
- LET_{ij}: The LET of the link between a vehicle V_i and a neighbor N^i_j.
- R^{SD}: The routes from V_S to V_D.

Algorithm:

```
for all V_i ∈ V do
    Find its neighbors N^i.
    Insert V_i into graph SbR.
    for all N^i_j ∈ N^i do
        Determine the LET of the link with V_i.
        Insert (N^i_j, LET_ij) into graph SbR.
    end for
end for
if ∃R^SD ∈ SbR. then
    for all R^SD_j ∈ R^SD do
        Calculate the RET_j of R^SD_j.
    end for
    Find the maximum RET_max in R^SD.
    if The number of RET_max > 1. then
        Find the most stable route which has the minimum hops.
    end if
end if
```

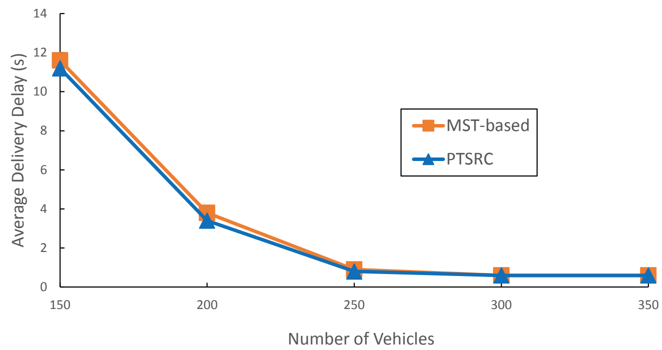

Figure 4. Average delivery delay vs. number of vehicles.

C. Simulation Results

Figure 4 shows the average delivery delay with varying numbers of vehicles. The MST-based PTSRC utilizes an MST until it is exhausted. On the other hand, the PTSRC recalculates its route every second. Without the excessive computation, the MST-based PTSRC almost achieves the same delivery delay as the PTSRC does.

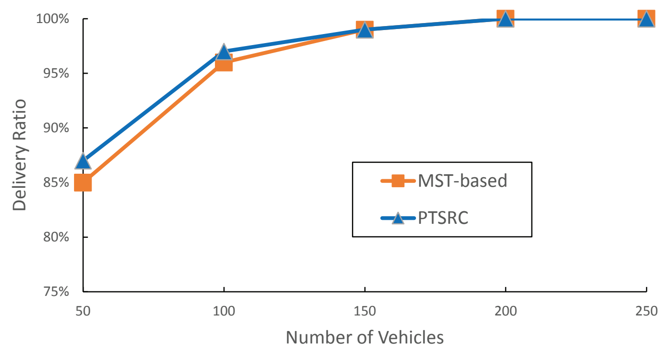

Figure 5. Delivery ratio vs. number of vehicles.

In the environment with the lower vehicle densities, the delivery ratios for both algorithms drop. The vehicles are harder to find neighbors in their transmission range, so it is more difficult to build the connected routes between the source and the destination. Figure 5 shows the delivery ratios with the varying numbers of vehicles ranged from 50 to 250. When the number of vehicles is 50, the delivery ratio is around 85%; while the number increases to 200 or more, the delivery ratio could reach 100%.

The time for calculating the most stable paths with the minimum number of hops is also examined. As shown in Figure 6, the MST-based PTSRC is more efficient than the PTSRC. When the number of vehicles is 350, the MST-based PTSRC only needs 13% of computation compared to the PTSRC. When the number of vehicles is larger, the number of available links between vehicles will increase. Therefore, the needed time for calculating pontential paths will be longer. Accroding to the results, the time complexity of the PTSRC increases rapidly with the higher vehicle densities. On the contrary, the MST-based PTSRC has better performance when the densities are higher.

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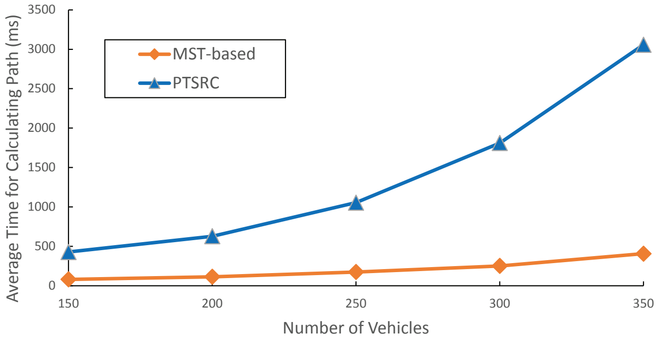

Figure 6. Average time for calculating paths vs. number of vehicles.

VII. Conclusion

Searching for a stable route for data transmission in VANETs is a challenge due to the highly dynamic characteristics of vehicles. In the self-driving vehicular environment, both LET and RET can be accurately measured, so it is feasible to determine communication routes with better stability for vehicles. Based on the simulation results, with the use of the maximum spanning tree, the MST-based PTSRC scheme reduces the needed computation drastically. The MST-based PTSRC successfully improves about 80% of the average calculation time compared to the original PTSRC.

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Vehicle MIMO System for High Reliability and Low Latency in NR-based eV2X

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***Abstract*—The 3rd Generation Partnership Project (3GPP) has recently developed enhanced vehicle-to-everything (eV2X) communication. The requirements of the eV2X service are significantly higher than those of existing V2X, with the required data transmission rates ranging from tens of Mbps to up to 1000 Mbps. In addition, communication should be performed with an extremely low error probability within a time delay of several to several tens of ms. In this study, a low-density parity-check code and 256 quadrature amplitude modulation (QAM), which are new radio technologies, are applied to meet the low-latency, high-reliability, and high-data-rate requirements of eV2X. In addition, we propose a vehicle multiple-input multiple-output system. The proposed system increases reliability through transmit diversity and lowers latency through a short transmission time interval. Simulation results show that the proposed system exhibits high reliability, high data rate, and low latency.**

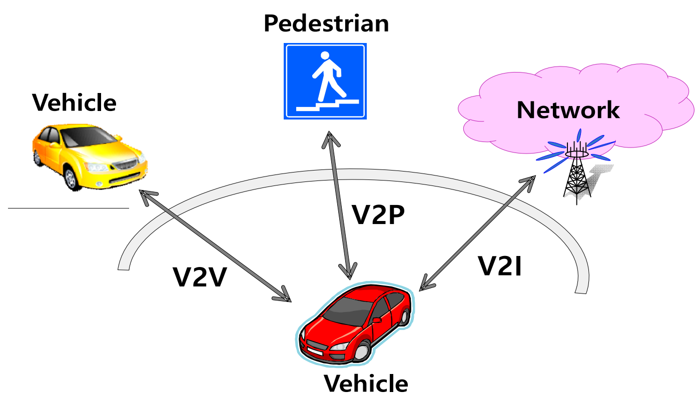
Keywords- eV2X; NR; sTTI; Transmit diversity.

I. INTRODUCTION

Communication technology has been used for communication between people and for providing information. However, in recent years, this technology has been applied to device-to-people and device-to-device communication. In particular, vehicular communication, which is also known as vehicle-to-everything (V2X), has several applications including navigation and driver assistance, travel information, congestion avoidance, fleet management, payment transactions, and traffic control and safety. As shown in Figure 1, V2X communication may occur in multiple contexts, i.e., vehicle-to-vehicle (V2V) communication, vehicle-to-pedestrian communication, and vehicle-to-infrastructure communication. These applications are referred to as cooperative-intelligent transport systems [1][2].

Autonomous vehicles will be developed in the future. These vehicles must exchange more data with neighboring vehicles, pedestrians, and road infrastructure with faster and higher reliability. The new requirement of autonomous vehicle service is limited by existing V2X communication technology, and there is a requirement for enhanced V2X (eV2X) technology to overcome this limitation.

The requirements of the eV2X service are significantly higher than those of existing V2X, with the required data transfer rates ranging from tens of Mbps to up to 1000 Mbps. In addition, communication should be performed with a considerably low error probability within a time delay of several to several tens of ms [3][4].



Figre 1. Types of V2X communication.

eV2X is being standardized in the 3rd Generation Partnership Project (3GPP), as shown in Figure 2. The 3GPP defines 5G technology from the Release 15 standard to be completion in June 2018. This technology consists primarily of long term evolution (LTE) and new radio (NR). NR is allowed to use a new physical channel structure and channel coding scheme with a new wireless access technology that is not compatible with existing LTE.

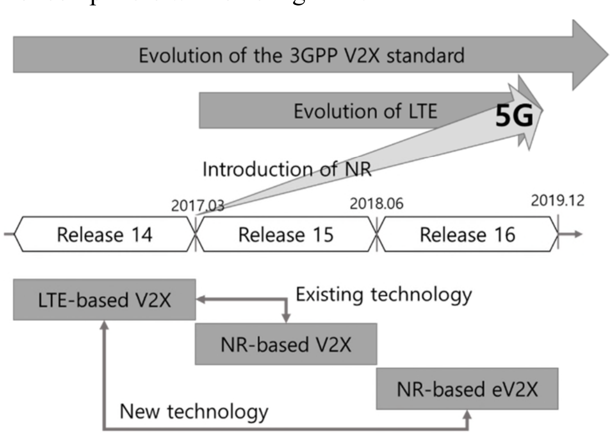


Figure 2. Standardization of eV2X in 3GPP.

In this study, a low-density parity-check (LDPC) code and 256 quadrature amplitude modulation (QAM), which are NR technologies, are applied to meet the low-latency, high-

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reliability, and high-data-rate requirements of eV2X. In addition, we propose a multiple-input multiple-output (MIMO) system that improves reliability through transmit diversity and reduces latency through a short transmission time interval (sTTI). The remainder of this paper is organized as follows: Section II presents NR-based eV2X communication. Section III describes the details of the proposed vehicle MIMO system. Section IV presents the performance analysis of the proposed scheme based on simulations. Section V states the conclusions of this study.

II. NR-BASED EV2X COMMUNICATIONS

In this section, we describe the LDPC code and 256 quadrature amplitude modulation (QAM), which are NR technologies.

A. LDPC

LDPC codes and polar codes, which are new channel coding techniques introduced in NR, can provide low latency and high reliability for eV2X. A channel coding scheme is a combination of error detection, error correcting, and rate matching as shown in Figure 3 [5]. In this study, the LDPC codes are applied as error correcting codes.

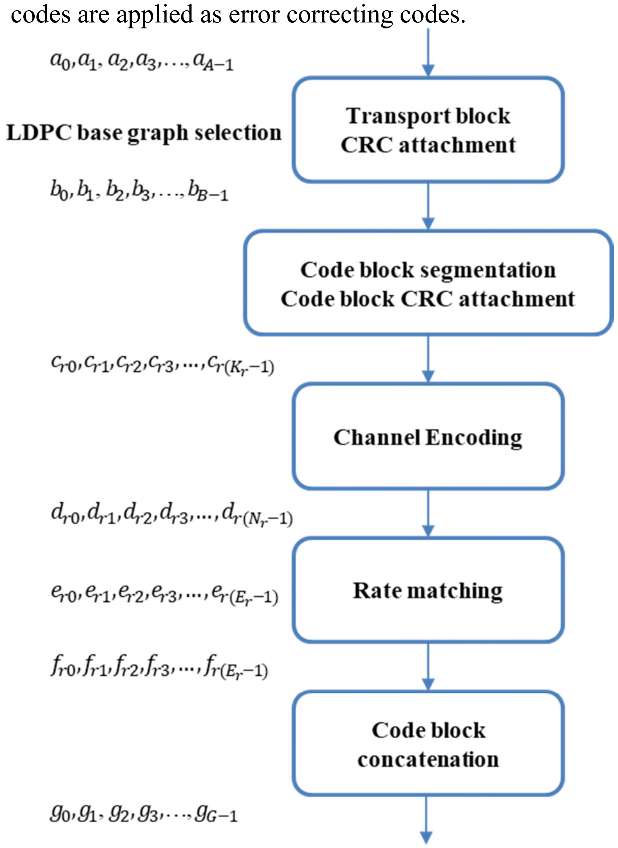

Figure 3. Transport block processing.

For the initial transmission of a transport block with a coding rate R and subsequent re-transmission of the same transport block, each code block of the transport block is encoded with either LDPC base graph 1 or 2 according to the following conditions:

- When (1) A ⩽ 292 or (2) A ⩽ 3824 and R ⩽ 0.67 or (3) R ⩽ 0.25, LDPC base graph 2 is used;
- Otherwise, LDPC base graph 1 is used,

where A is the transport block size (TBS). Table I summarizes the LDPC base graph selection.

TABLE I. LDPC BASE GRAPH SELECTION

TBS / Code rate	TBS ≤ 292	292 < TBS ≤ 3824	TBS > 3824
R ≤ 0.25	Base graph 2		
0.25 < R ≤ 0.67	Base graph 2		Base graph 1
R > 0.67	Base graph 2	Base graph 1	

For LDPC base graph 1, a matrix of $\mathbf{H}_{\mathrm{BG}}$ has 46 rows with row indices $i = 0,1,2,\ldots,45$ and 68 columns with column indices $j = 0,1,2,\ldots,67$. For LDPC base graph 2, a matrix of $\mathbf{H}_{\mathrm{BG}}$ has 42 rows with row indices $i = 0,1,2,\ldots,41$ and 52 columns with column indices $j = 0,1,2,\ldots,51$. The elements in $\mathbf{H}_{\mathrm{BG}}$ with row and column indices are of value 1, and all other elements in $\mathbf{H}_{\mathrm{BG}}$ are of value 0.

The matrix $\mathbf{H}$ is obtained by replacing each element of $\mathbf{H}_{\mathrm{BG}}$ with a $Z_c \times Z_c$ matrix, according to the following steps:

– Each element of value 0 in $\mathbf{H}_{\mathrm{BG}}$ is replaced by an all zero matrix $\mathbf{0}$ of size $Z_c \times Z_c$;

– Each element of value 1 in $\mathbf{H}_{\mathrm{BG}}$ is replaced by a circular permutation matrix $\mathbf{I}(P_{i,j})$ of size $Z_c \times Z_c$, where i and j are the row and column indices of the element, respectively, and $\mathbf{I}(P_{i,j})$ is obtained by circularly shifting the identity matrix $\mathbf{I}$ of size $Z_c \times Z_c$ to the right $P_{i,j}$ times. The value of $P_{i,j}$ is given by $P_{i,j} = \mathrm{mod}(V_{i,j}, Z_c)$. The value of $V_{i,j}$ is given according to the set index i_{LS} and base graph. $\mathbf{H}_{\mathrm{BG}}$ is given according to tables 5.3.2-1 and 5.3.2-2 in 3GPP TS 38.212 [5].

After the parity check matrix is obtained, we generate the parity bit $\mathbf{w} = (w_1, w_2)$ such that $\mathbf{H} \times \begin{bmatrix} \mathbf{c} \\ \mathbf{w} \end{bmatrix} = \mathbf{0}$, where c is the bit sequence input for a given code block to channel coding; $\mathbf{0}$ is a column vector of all elements equal to 0.

The parity bits are calculated using Richardson's efficient and Raptor such as LDPC, as shown in Figure 4.

Step 1) Richardson's Efficient LDPC: $w_1 = (w_1^1, w_1^2)$

The matrix is divided into A, B, C, D, E, and T, as shown in Figure 5 $\boldsymbol{w_1}$ is calculated using

$$w_1^{1^T} = \phi^{-1}(-ET^{-1}A + C)c^T \tag{1}$$

$$w_1^{2^T} = -T^{-1}(Ac^T + Bw_1{}^T) \tag{2}$$

where $\phi = -ET^{-1}B + D$.

Step 2) Raptor like LDPC: w_2

The matrix is divided into A, B, C, O, and I, as shown in Figure 6. w_2 is calculated using

$$w_2{}^T = -C(c \;\; w_1)^T \tag{3}$$

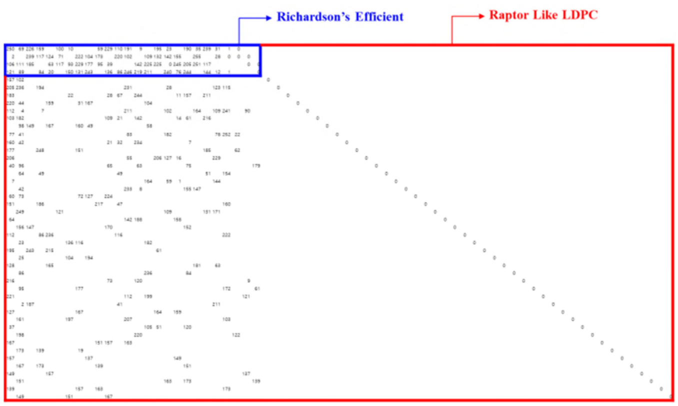

Figure 4. LDPC base graph 1: i_{LS}.

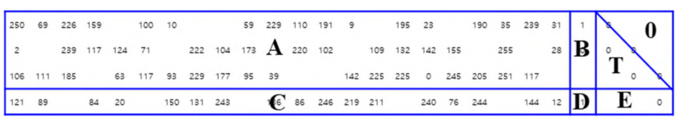

Figure 5. Richardson's Efficient.

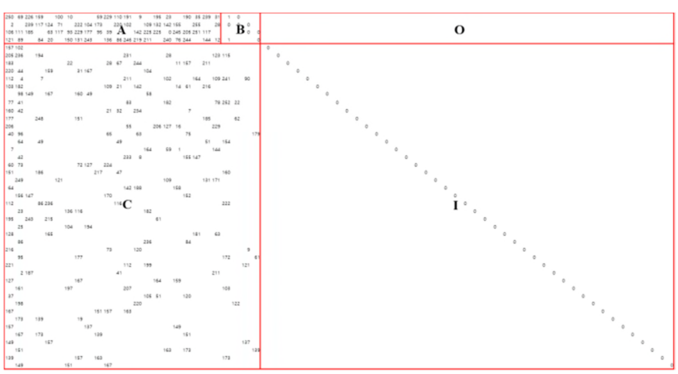

Figure 6. Raptor like LDPC.

B. 256QAM

256 QAM can be applied in order to provide a high data rate for eV2X. Figure 7 shows the constellation of 256 QAM. The eight input bits of 256 QAM, $(i), b(i+1), b(i+2), b(i+3), b(i+4), b(i+5), b(i+6), b(i+7)$, are mapped to complex-valued modulation symbols x, given below, as per the previous studies [6].

$$x = \frac{1}{\sqrt{170}}\{(1-2b(i))[8-(1-2b(i+2))[4-(1-2b(i+4))[2-(1-2b(i+6))]]] + j(1-2b(i+1))[8-(1-2b(i+3))[4-(1-2b(i+5))[2-(1-2b(i+7))]]]\} \tag{4}$$

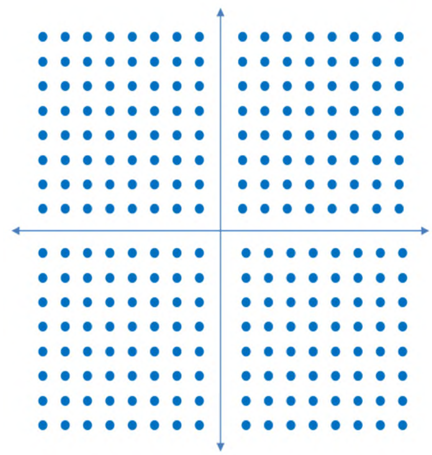

Figure 7. 256 QAM CONSTELLATION.

Therefore, 256 QAM improves the wireless transmission efficiency by 8/6 (or 1.33) times with 8 bit/symbol transmission of 256 QAM in 6 bit/symbol transmission of existing 64 QAM.

III. VEHICLE MIMO SYSTEM

In this section, we propose a vehicle MIMO system that improves reliability through transmit diversity and reduces latency through sTTI.

A. Transmit diversity

The eV2X service requires higher reliability and larger communication range in several use cases. All these requirements need physical layer enhancements. Transmit diversity can provide a gain on transmission reliability and potentially enlarge the communication range.

The symbols sent from two antennas, over two paired single-carrier frequency division multiple access (SC-FDMA) symbols form space time block coding (STBC), are as shown in Figure 8 [7].

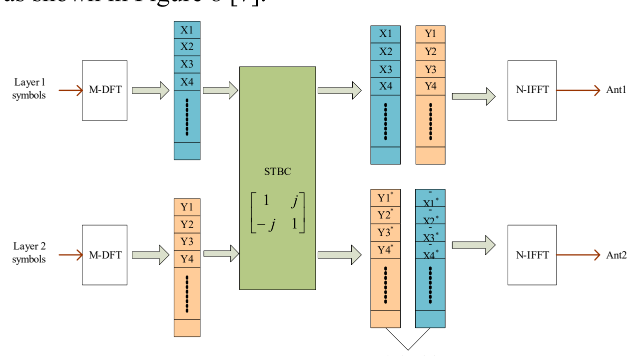

Figure 8. STBC transmit diversity.

B. *sTTI*

TTI is the time interval at which the transport blocks are scheduled and generally corresponds to the time required to transmit one transport block. TTI is defined as 1 subframe corresponding to 1 ms in the LTE standard.

As specified in Release 14 for V2V communication, the number of sidelink demodulation reference signal (DMRS) symbols per subframe is increased to 4 to combat a large Doppler effect in a high-speed scenario. For slot level short TTI, the structure of the second slot is a suitable choice where two DMRS symbols are evenly distributed in the time domain and a guard symbol is at the end.

In addition, STBC requires even number of SC-FDMA symbols, which can obtain full diversity gain. Therefore, the slot level sTTI is constructed as shown in Figure 9.

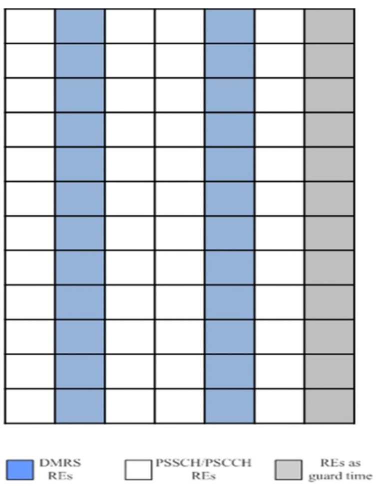

Figure 9. Structure of slot level sTTI.

The latency according to the TTI length is determined based on the frame alignment time by a 1/2 TTI time length, the processing time in each terminal or the base station and the data transmission time in a physical layer by one TTI time length, and the hybrid automatic repeat request (HARQ) BLER $(p = 0.1)$ is the increase due to retransmission determined by round trip time (RTT). Assuming that the processing time is 0.2 ms, the latency of the user plane at 5G with time length is

$$0.5T_{TTI} + 2 \times 0.2 + T_{TTI} + p \times RTT\ [ms] \quad (5)$$

Assuming that RTT is equal to 8 TTI, the final latency in Eq. (5) is

$$0.4 + (1.5 + 8p)T_{TTI} \quad (6)$$

IV. Simulation Model and Performance Analysis

In this section, we analyze the performance of the vehicle MIMO system. The simulations are based on the NR-based V2V system [8], and the simulation parameters are shown in Table II.

TABLE II. SIMULATION PARAMETERS

Parameters	Assumptions	
Carrier frequency	6 GHz	
Number of antenna	$1 \times 2, 2 \times 2$	
Vehicle speed	Urban: 15 km/h	Freeway: 140 km/h
Channel model	Urban: UMi LoS	Freeway: UMa NLoS
Modulation	16, 64, 256 QAM	
Channel coding	LDPC 1/2	

Figure 10 shows the BLER performance according to the antenna configuration. Based on the BLER 10^{-1}, the performance of transmit diversity is improved by 1.2 dB and 1 dB in urban areas and highways, respectively.

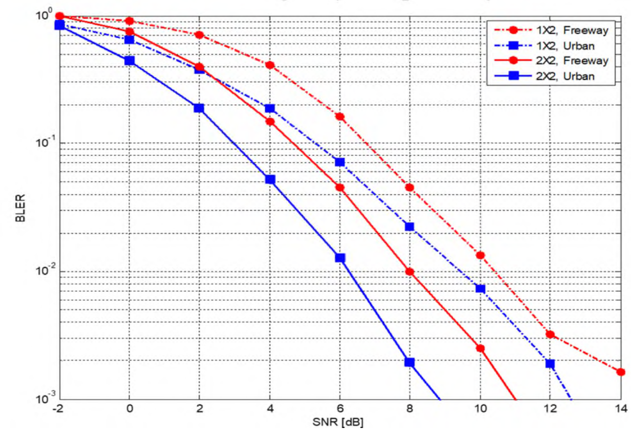

Figure 10. BLER performance according to antenna configuration.

Figures 11 and 12 show the throughput performance according to the modulation in the urban areas and highways, respectively. It can be seen that the maximum throughput of 16, 64, and 256 QAM is 2.43 Mbps, 3.60 Mbps, and 5.15 Mbps, respectively.

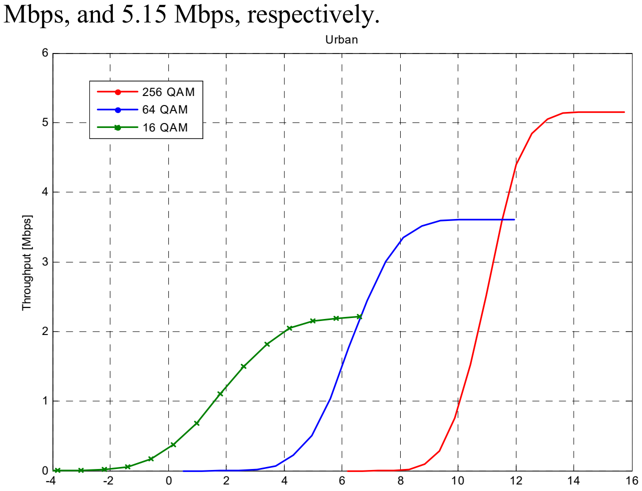

Figure 11. Throughput performance according to modulation in the urban area.

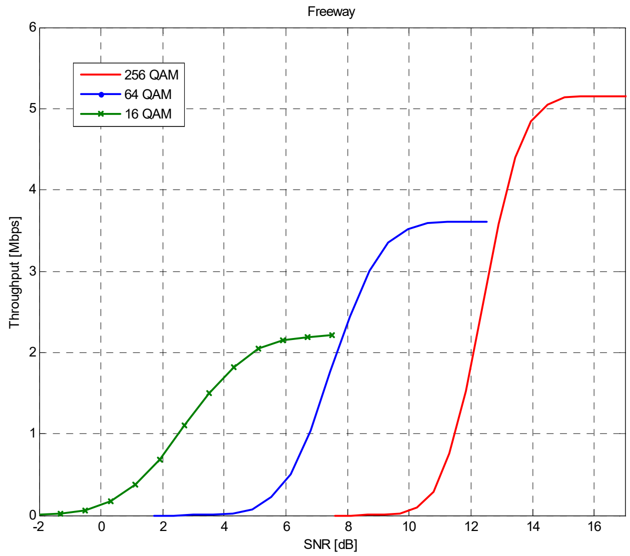

Figure 12. Throughput performance according to modulation in the freeway.

Figure 13 shows the delay time of the user plane according to the given TTI length using (6). The latency of 0.5 ms TTI compared to 1 ms TTI is reduced by 0.61 and 0.57 times, for p = 0.0 and 0.1, respectively.

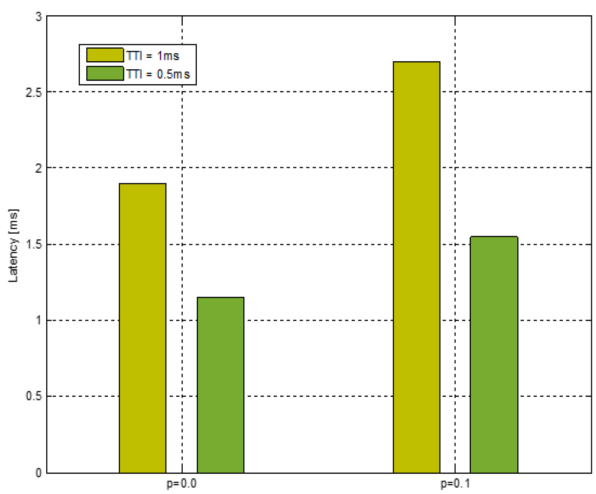

Figure 13. User plane latency for different TTI lengths.

V. Conclusion

In this study, the LDPC code and 256 QAM of NR technology were applied to meet the low latency, high reliability, and high data rate requirements of eV2X. In addition, we proposed a vehicle MIMO system. The proposed system increases reliability through transmit diversity and lowers latency through sTTI. Simulation results show that the proposed system has high reliability, high data rate, and short latency.

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Jammer Localization Method using Degradation of GPS C/No Measurements

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***Abstract*— In this paper, we present the Global Positioning System (GPS) jammer localization method using the carrier-to-noise density (C/No) measurements of the commercial GPS receivers, which are already installed nationwide in Korea. The jamming power directly affects the C/No measurements of GPS signals. Accordingly, we precisely make the C/No profiles of the GPS receivers correspond to the jamming power under jamming test environment. Then, the Received Signal Strength (RSS) of the jamming can be estimated by comparing the degraded C/No measurements and the corresponding C/No profile of the respective station. Finally, we determine the jammer location by using the RSS of the respective station and the propagation prediction model of the jamming signal.**

Keywords- GPS; Jammer; Localization; C/No.

I. INTRODUCTION

Even though GPS signals are normally robust to jamming due to spreading gain using the code division access scheme, it can be disturbed and can malfunction if the jamming exceeds the spreading gain [1][2]. In particular, the jamming is very critical threat to the unmanned autonomous applications using GPS navigation [3]. The direction finding system is generally used to locate the jammer source, but it is highly costly and should be deployed in the specific station [4]. Therefore, in this paper, we present a GPS jammer localization method using the C/No measurements of the commercial GPS receivers, which are already installed nationwide in Korea. The simulation demonstrates that the proposed method estimate GPS jammer location by using the C/No measurements. The paper is organized so that Section II describes the block diagram and localization algorithm. In Section III, we present the simulation results of the proposed method. Finally, the conclusion is drawn in Section IV.

II. PROPOSED METHOD

A. Block diagram

Figure 1 shows the block diagram of the proposed scheme. The jamming power can be estimated by the C/No measurements of GPS signals because they are directly affected by the degree of jamming. Accordingly, we previously make the C/No profiles of the GPS receivers correspond to the jamming power through the precise jamming test. If we detect the degradation of the C/No measurements of the GPS receivers installed and operated in various stations, we estimate the RSS of the jamming by utilizing the corresponding C/No profile of the respective station. Then, we configure the candidate area including the jammed stations and divide it into the small cells. The cell size is defined as the resolution of the jammer location. We calculate the average value and variance of the transmitted power at all cells within the candidate areas by using the RSS of the respective station and the propagation prediction model of the jamming signal. Finally, we determine the location of the GPS jammer as the cell position within the candidate areas having the minimum variance of the transmitted (TX) power.

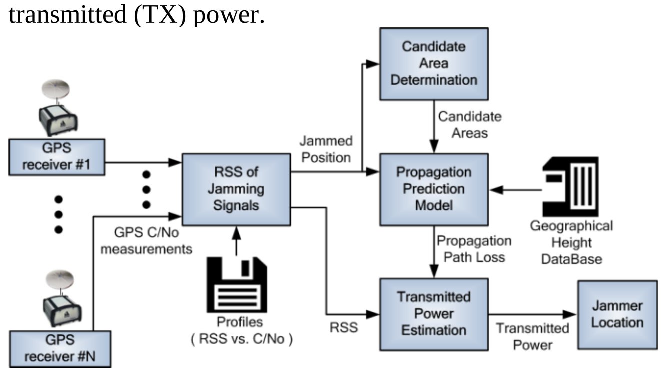

Figure 1. Block diagram of the proposed method.

B. Localization Algorithm

Figure 2 illustrates the algorithm to determine the jammer location. There are many propagation path loss values between the number of jammed positions and the cell position. Then, we can estimate the number of TX powers

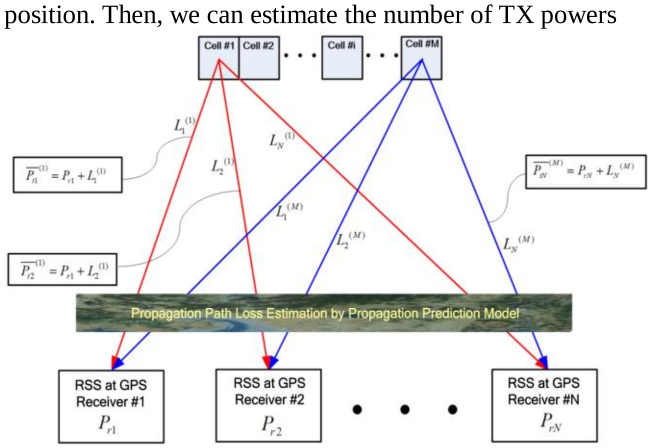

Figure 2. Localization algorithm of the proposed method

corresponding to the number of jammed positions at each cell. Therefore, the cell having the minimum variance of the estimated TX powers means the estimated optimum location of the jammer within the candidate area including the jammed stations. In this paper, the propagation prediction by the Longley-Rice model is used to estimate the propagation path loss [5].

III. SIMULATION RESULTS

Firstly, we make the C/No profiles of the GPS receivers corresponding to the RSS of the jamming, as shown in Figure 3. Although the C/No values measured from the GPS receiver are various, we use the average value (green color) of C/No values having about 50 dB-Hz (light-green color) for comparing the degraded C/No from the jammed receiver.

C/No PRN#28	C/No PRN#5	C/No PRN#13	C/No PRN#18	C/No PRN#20	C/No PRN#24	C/No PRN#21	C/No PRN#15	C/No AVR	RSS [dBm]
30.83	43.00	45.00	48.00	49.67	50.00	50.50	51.67	50.06	-107
30.33	44.00	46.00	48.00	49.67	50.00	50.00	51.50	49.89	-106
28.50	44.00	45.67	48.00	49.33	50.00	49.83	52.00	49.72	-105
29.17	44.00	46.00	48.50	49.50	50.00	51.00	52.00	50.17	-104
•	•	•	•	•	•	•	•	•	•
20.17	26.67	35.83	34.83	29.00	37.00	39.00	40.00	35.00	-64
20.50	26.83	36.00	34.00	29.17	36.17	37.00	39.50	34.11	-63
0.00	27.00	35.67	33.17	28.67	35.83	35.83	39.00	33.44	-62
0.00	27.83	34.00	33.00	28.67	35.00	34.50	38.00	32.72	-61
0.00	28.67	32.83	32.33	29.17	34.33	34.17	37.67	32.56	-60
6.83	28.67	30.67	32.00	28.67	33.83	33.83	33.67	32.11	-59
0.00	28.33	29.17	31.67	21.50	33.33	33.00	34.67	29.28	-58
0.00	28.50	29.67	31.17	28.67	33.33	34.00	31.00	32.00	-57
6.83	28.17	29.67	30.17	28.67	33.83	32.50	29.50	31.67	-56
0.00	28.00	29.50	30.00	29.17	33.83	31.00	27.33	31.33	-55
6.83	20.50	27.83	30.00	28.67	33.33	30.33	29.17	30.78	-54

Figure 3. C/No profiles of the GPS receivers corresponding to the RSS

It is assumed that 11 receivers are jammed by the jamming of 1KW effective isotropically radiated power (EIRP) via 1575.42MHz at the position (LLH : 36.8499° / 127.2257° / 560m) near Chonan city in Korea. The RSS values at the stations installed in the commercial GPS receivers are displayed in Figure 4.

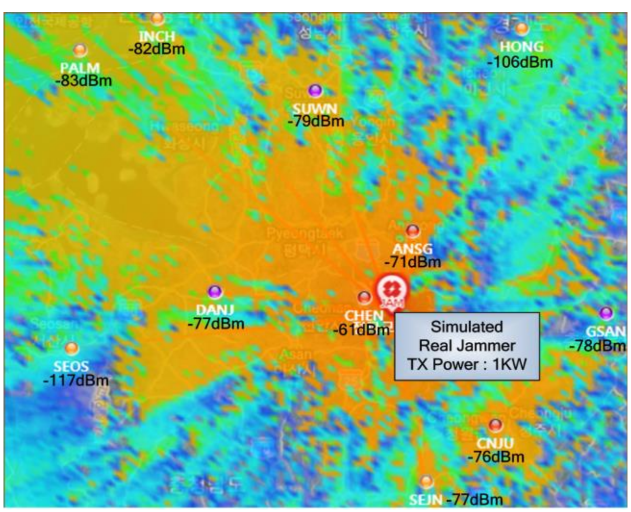

Figure 4. Simulated RSS by simulated jammer power

Figure 5. Estimated jammer location and power

Figure 5 shows that the proposed method estimates 1.9 KW power with about 3 dB error at the jammer location using the RSS of the respective station and the propagation prediction of the Longley-Rice model, on the assumption that the RSS are accurately estimated.

IV. CONCLUSION AND FUTURE WORK

In this paper, we presented the GPS jammer localization method by using the degradation of C/No measurements of the GPS receivers already installed nationwide in Korea. The simulation showed that the proposed method estimates the GPS jammer location under the condition that the RSS values are accurately estimated by the degraded C/No. This result showed that this method could be used effectively to locate the jammer. Furthermore, future studies will be aimed at improving the reliability of the proposed method by performing experiments under a realistic environment.

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