Centralised Multihop Routing Techniques for Device-to-Device Communication

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***Abstract*—Device-to-Device (D2D) communication is a new paradigm in mobile networks that allows users in proximity to each other to communicate directly, without passing data through a central Base Station. However, due to users' mobility and their location, the users may be far away from each other and this can lead to low-performance data transmission. The multihop approach allows the source user to relay data to the destination user through hop by hop. The advantages of D2D communication can be fully exploited in a multihop communication environment given that the single-hop communication usually limits the communication scope to a specific geographic area. However, routing in multihop cellular D2D networks raises performance-related challenges, versus a traditional cellular network, if non-optimal routes decisions are made. The contribution of this paper is a short review of multihop D2D networks and then a selection is made to discuss more details on a number of centralised routing techniques. The work is still in progress and tries to identify some open research issues to be considered in the future. Therefore, this work will serve as a base model for future performance comparisons, made by simulations between multihop routing techniques.**

Keywords-multihop; routing; device-to-device; SDN; IoT; v2v; overhead.

I. INTRODUCTION

In traditional cellular communication, if two users close to each other want to communicate, the source User Equipment (UE) has to relay its message to a Base Station (BS), and the BS relays the message to the destination UE. Due to the user's mobility or physical obstruction, the communication session may suffer from varying signal quality, resulting in low data transfer. In addition, more battery life is consumed by the UEs to communicate between each other.

Device-to-Device (D2D) communication allows users in proximity to each other to exchange data directly without passing or relaying data to the BS. Moreover, this direct communication can be controlled by the BS, i.e., the BS will have responsibility for establish and authorize the D2D connection among users. Additionally, the BS can handle the Quality of Service (QoS) policies and the mobility management. D2D communication has been approved as a part of the cellular communication systems since LTE (Long-Term Evolution) Release 12 [1].

This direct communication has been offered by other technologies, such as Bluetooth, ZigBee or Wi-Fi [19], but these technologies are limited to short ranges (approximately 100 meters) [15]. In addition, interference issues exist, given the operating spectrums (The industrial, scientific and medical (*ISM*) band 2.4 GHz and 5 GHz). On the other hand, the communication range in D2D communication is about 1-2 Km. The interference issue could be handled in a centralised way due to the presence of BS [15].

However, when two UEs are not in proximity to each other, the result is a low throughput in the D2D communication session. The multihop approach allows the source UE to relay data to the destination UE through hop by hop. The multihop communication can increase the D2D communication coverage and possibly increase the throughput rate.

The advantages of multihop D2D communication can be fully realized in the public safety and commercial applications. In case of natural desasters, when the cellular infrastructural is partially unavailable or when the network is congested, the multihop approach provides an alternative solution for the mobile node by relaying the emergency messages to evacuation centers through other mobile terminals.

Many Internet of Things (IoT) applications require the transmission of data between a set of devices to a central station for processing or storage. Moreover, most IoT equipment is capable for short-range transmission due to energy constraints. Therefore, relying the information through intermediary nodes is required. The integration of cellular and multihop networks provides reliability, and flexibility, and guarantees QoS.

In multihop D2D communication, D2D devices which are out of the coverage could use the intermediary nodes to relay data to the infrastructure network or to communicate with other end-users, resulting in overall network expansion and increased network coverage.

Moreover, the multihop communication supports a number of applications, such as broadcast information (e.g., related to collisions on the roads) between vehicles, in vehicle-to-vehicle (V2V) network, or broadcast messages to specific nodes in a geographical area in the Internet of Things network.

Due to node mobility and dynamic network topology, routing in multihop D2D networks is a critical issue if wrong routing decisions are made. An efficient routing scheme needs to be designed for better performance in terms of higher network capacity and efficient energy consumption.

The rest of this paper is organised as follows. Section II gives an overview of the D2D multihop network. Section III

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addresses the centralised multihop routing schemes. A number of research challenges are presented in Section IV. Finally, the conclusion and future works are provided in Section V.

II. THE DEVICE-TO-DEVICE MULTIHOP NETWORK

This section presents a short introduction to Device-to-Device communication and multihop network. The first subsection describes the D2D communication and the types of communication in the cellular network. The multihop network classifications and relay types are provided in the second subsection.

A. Device-to-Device Communication

In a traditional cellular network, a user node communicates with the BS via a single-hop path. However, despite the fact that this type of communication provides good delay characteristic, it suffers from traffic overloading, as the traffic demand grows rapidly [2]. One solution is to deploy more BSs inside a cell, but this leads to increased costs of installation and management [3]. Thus, the D2D communication can be considered as a potential candidate technology to handle the network capacity/coverage problem [4]. The 3rd Generation Partnership Project (3GPP) LTE Release 12 indicated that two devices in proximity to each other could communicate directly. This kind of communication can be seen in different network scenarios [5]: *In-coverage scenario* when both UEs are under the same network coverage, *Partial coverage scenario* - one of UEs is outside the network coverage, and the *Out of coverage scenario* when both UEs are outside the network coverage. In releases 13, 14 and 15, the UE which is out of the network coverage can use another nearby device which is within network coverage as a relay to communicate with the network. There are two types of D2D communications, either, i.e., supervised (under the control of the BS) or unsupervised (when a node is out of the coverage of the cellular network). In the supervised communication, the BS controls the communication and guarantees performance and security by complete control over the control plane and the data plane [7][8]. The control plane is responsible for the establishment of a connection, its maintenance, termination and also enforces security policies, e.g. authentication, encryption. Additional functions of the control plane include collision avoidance and mobility management. Moreover, the data plane is responsible for resource allocation based on control plane instructions. For the supervised communication, the communication can be either: *Network-based communication*, i.e., all devices are under the full control of a centralised node (BS); or *Network-assisted communication*, i.e., all devices can make decisions autonomously, but based on the measurements provided by the centralised node. Moreover, in unsupervised-communication, the devices are stand-alone and work exactly like adhoc networks. These networks do not have any constraints due to the failure of the centralised entity, e.g. the (BS). For example, in an adhoc networks, failure of any node has an insignificant effect on the overall network performance.

The only difference between adhoc routing and unsupervised D2D routing is in the usage of spectrum frequency bands. D2D nodes can use both the licensed and/or the unlicensed bands while adhoc nodes can only use unlicensed bands.

B. D2D Multihop Communication

In a multihop network, a UE communicates with another user by relaying the data hop by hop, through intermediate nodes until reaching the destination UE. Thus, the UEs can communicate in one of the four modes [6]: *Single-hop D2D communication, Multihop Device-to-Infrastructure (D2I)/Infrastructure-to-Device (I2D) communication*, *Multihop D2D communication*, and traditional cellular communication. In single-hop communication, two devices are in the proximity of each other and directly communicate without needing any relay. For the multihop D2I/I2D communication, the multihop route is established between the node and the network service entity, i.e., BS.

In the multihop network, the UEs communicate through an intermediate node that acts as a relay. Thus, the type of relay could be classified into: The Network Relay: The relay used by multihop D2I/I2D routing scheme, as this relay helps the UEs to communicate with the BS. This is further classified into *fixed network relay*, *mobile network relay*, and *Device Relay*. The fixed network relay is static and installed by the network operator. A mobile network relay can be a user node, which provides services for data forwarding between the BS and the other users.

III. MULTIHOP ROUTING TECHNIQUES

The multihop routing decision could have been taken by the centralised entity (BS) or *distributed,* when each node could take the route decision autonomously, while taking into account the presence of other nodes.

The multihop D2D routing schemes could be classified into *incentive-based, security-based, content-based, location-based* and *flat topology-based routing* [9]. The security-based routing is used for security concern when the content-based routing used when the frequent data has to be shared among users (e.g., video). The incentive-based routing is used when the users are encouraged to participate in relaying the data of other nodes by using some incentive.

In the location-based routing scheme, a centralised entity (location servers) has location information for all nodes. The route decision is either take by nodes using the location information (distributed routing strategy) or with a centralised approach by BS. In the flat topology-based routing case, the network nodes do not have any specific structure (e.g., cluster), nor have any location awareness mechanism.

Another classification based on *route mechanism discovery* is presented below:

- Reactive routing (on demand-driven): the information about the possible paths between end devices is obtained after a transmission request is issued in the network.

- Proactive routing (table-driven): each node always maintains a routing table containing routes for different destinations and the updates of routing tables are done regularly.

- Hybrid routing: both the reactive and proactive routings operate at the same time. Hybrid routing divides networks into local neighborhoods (known as zones).

- Adaptive routing: in this scheme, the routing mechanism switches between reactive and proactive routing depending upon network dynamics and their network zones.

Next, we review some related works for a multihop routing scheme.

In case the nodes in the network do not have any specific structure or any location awareness mechanism, then the flat topology routing protocols will be integrated into the network.

In this work, we only focus on centralised flat topology-based routing. The centralised flat topology routing schemes for multihop D2D communications are categorised into reactive and proactive routing (see Table I).

In Centralised-Based Routing schemes, a centralised entity (BS) regularly gathers neighbor nodes information from all the network nodes in order to construct and update the network topology. Serval work routing schemes have been proposed based on centralized reactive approach: *multihop cellular network* (*MCN*) [10], *cellular based source routing* (*CBSR*) [11] and A *Base-centric routing* (BCR) [12].

In the *Multihop Cellular Network* (*MCN*) routing [10], every node maintains a neighbours table based on the "HELLO" message exchange procedure. The entry of the table includes the received SNR (signal to noise ratio) of the neighbor nodes; if there is a change in the received power level, then updates will be sent to the BS. Thus, the BS has an up-to-date database about all the links in the cell.

The MCN protocol also supports the detection of a broken route. Thus, consider the following scenario when the route between two nodes A and B is (A – X – Y – B), where X and Y are intermediate nodes. Suppose that when X receives a packet from A to B, (the next hop form X is Y), X detects that the link X-Y is no longer available (e.g. timeout of the HELLO message from Y). Here, X will send a route request to the BS; then, the BS responds with a new route update to X and A (to update the cache route at A). However, this route update will result in a high routing overhead, which may severely degrade the network performance.

Another variant of the proactive centralised routing is *Cellular Based Source Routing* (*CBSR*) [11]. In this scheme, each node contains a table of its neighbor nodes and periodically exchanges HELLO packets with its neighbors. The HELLO packets contain current address and traffic load information. After receiving a HELLO message, each node updates its neighborhood table and periodically reports it to the BS. The report update contains neighbor load, link quality (between the sender node, of HELLO and its neighbor) and HELLO packet receive instant of time.

Using the information from reported neighbourhood table, the BS builds network topology based on two tables, the node table, and adjacency table. The node table stores information about each node in the cell. The adjacency table contains details about each node with its neighbours. In addition, the adjacency table includes additional information of the distance (hop count) between nodes if the hop count is 1 than the two nodes are adjacent.

If two UEs want to communicate, the source node (UE) first checks its routing table cache. If some routes are available, the source UE chooses one of the routes (if there is more than one route available) and start sending the data packet. In case there is no route information available, then the UE sends a unicast route request (RREQ) to BS, with source and the destination addresses as parameters. Then BS replies with all available routes via RREP message, or otherwise, an error route (RERR) will be returned in case of no route available.

A *Base-Centric Routing* (BCR) protocol is proposed in [12]; it is a hybrid of demand-driven and table-driven routing. The BS draws the network topology by the table driven method and can thus compute paths. The nodes use the demand-driven approach to find the route to the required destinations. These nodes send a route request to the BS, and if there is no route from BS, then the node broadcast route request like in Adhoc On-demand Distance Vector (AODV) routing protocol [16].

The designed BCR protocol is based on two ideas: the *first* is that the BS tracks the intra-cell network topology, and lists the user's nodes that reside in the cell. The *second* is that the mobile node sends a route request on demand to avoid extra overhead.

Adaptive centralised routing: In adaptive centralised routing, a central controller (usually BS) is responsible for all routing decisions.

A *Centralised Adaptive Routing* (CAR) is proposed in [6]. The algorithm switches between reactive and proactive routing based on network conditions, e.g., node density, average node mobility or traffic load [13][14].

The authors of [6] introduced six types of messages involved in building the route:

- RREQ: it is send by the node to BS requesting a route to another node.
- B-RREQ: the BS broadcast B-RREQ all node to initial neighbourhood discovery phase.
- HELLO message: the node exchange HELLO message for updating their neighborus list.
- U-RREP: after updating the neighbourhood list, the nodes broadcast the updated list to BS.
- Route reply: after the BS received the updated neighbours list from the nodes. The BS computes the route between source and distention.
- B-RREP:

In centralised proactive routing, as shown in Figure 1, each node periodically exchanges HELLO packets with each other in order to update the neighbour table, and broadcast the neighbour table (U-RREP message) to the BS. When a node wants to communicate with another node, it sends a route request (RREQ) packet to the BS. The BS either will provide a route if available (route reply message), or establishes a traditional cellular connection between them.

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For the centralised reactive routing, when a node wants to communicate with another node it sent routes (RREQ message) to request to the BS as shown in Figure 2. Upon receiving a route request packet from a node, BS broadcasts the neighbour's list request (B-RREQ message) to all nodes in order to update the network topology by exchange HELLO messages between them.

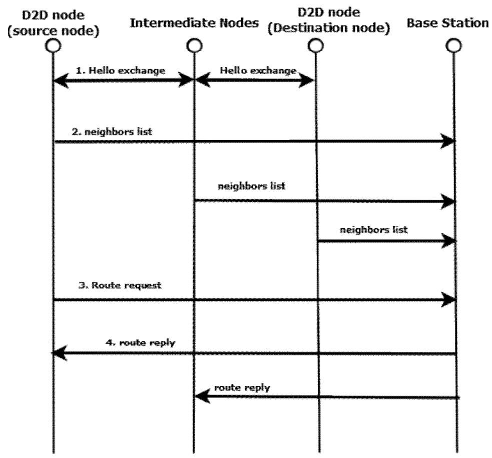

Figure 1. Centralised proactive scheme

Next, all the nodes exchange HELLO packets and then send the updated neighbour list to the BS. The BS computes the route to the destination and sends the routing message to participating nodes (step 5 in Figure 2). In order to further reduce the routing overhead, the authors proposed Node Level Decisions that allow the nodes to decide whether to participate in the route discovery or not, based on their remaining battery energy and current traffic.

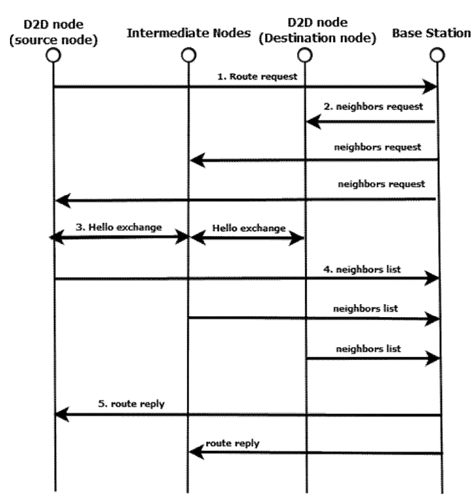

Figure 2. Centralised reactive scheme

In adaptive routing, the routing algorithm switches between the proactive and reactive scheme depending on the different network conditions (e.g., node density and traffic load). The authors proposed a threshold in order to avoid a ping pong effect from switching between the reactive and the proactive scheme (see Figure 3).

When the traffic load is above a given threshold 2, the routing switches from reactive to proactive. However, when the traffic load is below the threshold 1 the routing switches from to reactive scheme. In addition, the oscillation timer is used with the threshold value in order to avoid switching fluctuation.

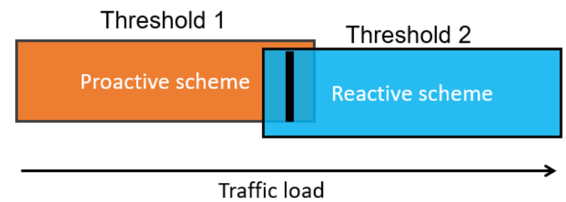

Figure 3. Threshold value

Authors introduced a number of features that could be integrated into the proposed protocol for reducing the routing overhead.

A. Node Level Decisions:

Each node autonomously decides about participation in the route discovery (i.e., neighborus discovery). The node level decision reduced the resources consumption (e.g., energy) in the route discovery phase. Serval criteria (e.g., energy and traffic load) are involved in node decisions. Authors classified the nodes based on residual energy. The nodes participate in the route discovery if residual energy is greater than 50%. Moreover, the node with residual energy less than 25% will never take part in the route discovery.

Another criterion is based on the change of the data traffic load by comparing the current load with the previous average load. When the current load is greater than 90%, then the node never participates in route discovery. However, if the current load is less than 75% and the previous average load is higher than 75%, then the node participates in the route discovery.

B. Variable route's timeout:

In order to break a route, the route expiration timer (timeout) that is defined as the minimum value of the link expiration timer among all links in the whole route is taken as the route timer. A node participates in route discovery only if the timer is greater or equal to the minimum required route timer.

C. Earlier stop message (ESTOP):

This message is broadcast by BS to inform nodes not to send any route request message due to a large number of messages received by the BS. The ESTOP message could reduce the routing overhead by limiting the number of nodes replying to a route request.

In order to provide a reliable connection and, in case the multihop route is not possible, then the BS will provide a traditional cellular link between the source and the destination node.

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Both the cellular mode and multihop D2D mode could be enabled on the user device. Through cellular mode, the UE report updated neighbours list and BS draw Network topology view and provided a suitable route to UEs. This could be seen as a separation of control plane and data plane where the control plane provides the decision of the data forwarding. Moreover, the data plane route the data traffic through multihop D2D.

Based on that, the authors in [15] proposed a multihop D2D SDN network architecture and the low-overhead routing (LODR) protocol. It is known that SDN separates the control plane from the data plane; decisions on the routing of the traffic flows are taken in the control plane; then, flow tables are installed in the forwarding nodes of the data plane.

The proposed architecture assumes that each UE has an OpenFlow capability installed. In addition, the SDN controller controls the forwarding behavior of multihop D2D UE. The authors proposed five procedures to route the data traffic in the multihop D2D network. These procedures include: how to handle an unknown route, add a new UE, installing, maintaining, and updating the routing flow in the multihop D2D, etc. The results show that the proposed procedures perform better then Open Link State Routing (OLSR) [17] in terms of control overhead.

TABLE I. COMPARISON OF CENTRALIZED MULTIHOP D2D ROUTING ALGORITHMS

Routing algorithm	Routing scheme	Simulation implementation	Simulation metrics
MCN[10]	Proactive	GloMoSim	Throughput (TCP,UDP)
CBSR[11]	Proactive	NS-2	Delay, Packet delivery ratio, Routing overhead
BCR[12]	Hybrid	GloMoSim	Throughput under UDP, TCP with/without mobility
CAR[6]	Adaptive	-	No simulation evaluation
LORD[15]	Proactive	CORE	Overhead, Routing convergence time

IV. CHALLENGES AND OPEN RESEARCH ISSUES IN MULTIHOP D2D ROUTING

Based on the works reviewed in Section III, there are several challenges and, at the same time, open research in multihop D2D routing protocols that need to be considered and solved in the design of the future protocols. This section identifies some of the research challenges in Multihop D2D routing protocols.

A. *Reduce Routing Overhead*

In centralised multihop routing, the nodes exchange HELLO messages (periodically or on demand) with each other in order to build/update the neighbor's list. This list is sent (periodically or on demand) to the BS, which creates a global view of network topology and computes the suitable/short path between source and destination in the multihop D2D network. This exchange of messages between the nodes (i.e., BS and UEs) consumes resources. For example, the nodes regularly update their neighbor's list and send it to the BS; such a scheme leads to high-energy consumption and high delay. Thus, the control messages should be reduced.

Therefore, an open research issue is *how to route the data in multihop D2D communication while assuring a low control overhead*.

B. *Applying SDN to Multihop networks*

In the SDN approach, the control logic of network nodes is logically centralised, which programs the whole network (e.g., adjust forwarding rules on network devices based on particular policies and protocols). Applying such approach brings a number of challenges, as indicated below.

The first issue is that UEs need to discover the controller. In some studies, there is an assumption that all network devices know about the controller. In other papers, firstly, the controller broadcasts its existence to all network devices. Moreover, the network devices (UE) can communicate with the controller in one hop or in a multihop fashion. In one hop communication, network devices connected to the controller directly via a wireless link (e.g., cellular link).

While in the multihop approach, the connected UEs communicate with the controller through intermediary nodes. Thus, the shortest path between the controller and network devices (UE) is important to meet the energy constraints of mobile devices.

Minimizing the control messages exchanged between the controller and mobile devices is another issue that should be handled when applying SDN to the cellular network. The control messages are important in reducing delay and optimising the energy consumption.

The controller can be implemented as a single centralised entity or a distributed approach. Selecting an appropriate type of the control plane implementation (centralised or distributed) can affect the performance of the network. The controller manages the overall network view and consequently provides the forwarding rules (based on information collected from network nodes).

Several optimisation problems can be identified, such as: a) the amount of information to be sent to the forwarding nodes; b) how frequently should the controller setup/update flow rules, in order to avoid too much control overhead but still keeping an enough fast response to the network dynamics; c) how frequently should be updated (at the controller level) the image of the current network topology.

C. *Failure Recovery Mechanism*

In the works reviewed in Section III, a centralised entity (e.g., BS) has a network view and provides suitable routes for UEs. In case of failure of a node (e.g., BS) or no route received, a backup recovery mechanism should be introduced. The authors of [12] proposed a backup mechanism when there is no route from BS. Then the node broadcast route request via AODV routing protocol.

Therefore, *introducing a failure recovery mechanism is important to provide a reliable, stable connection between UEs.*

V. CONCLUSION AND FUTURE WORKS

In the single-hop D2D communication, the users are limited to communicate with only nodes in the proximity. However, in cases when the UEs are not in the vicinity, a UE has to relay data to a destination through a multihop route. In a centralised multihop network, an updated neighborus list is collected by the BS (periodically or on demand); then, the BS will create a global view of the network topology and will provide the suitable routes to UEs.

Several challenges for D2D centralized routing have been identified in this paper.

The control messages exchange between UEs and BS should be further minimized, aiming to meet energy constraints on UEs. In addition, in order to provide a stable connection between UEs, a backup mechanism should exist, to act in case of failure of the centralised entity or if no route is provided. Applying SDN to the multihop network is a promising approach that should be handled carefully in terms of communication between network nodes and controller and the control plane implementation.

As a future work, a simulation model and a tool (e.g., NS-3) will be developed for D2D routing, to implement the proposed centralised schemes. The simulations will provide as results a comparison of solutions, in terms of routing control overhead (in the control plane) and packet delivery ratio, network throughput and delay (in the data plane).

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