Optimal Network Selection for Mobile Multicast Groups

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***Abstract*—Mobile devices are typically equipped with multiple access network interfaces, supporting the coexistence of heterogeneous wireless access networks. The selection of an optimal set of serving mobile networks for multicast streams is a challenging problem. We consider a network selection problem for multicast groups of mobile clients that operate in a heterogeneous wireless access network environment. We present a solution to this problem with an optimal allocation of mobile users to multicast groups when multiple mobile networks are available for operation. This solution is suited for small scale networks and can be used as reference for complex networks.**

***Index Terms*—Wireless networking, mobile network selection, decentralized algorithms.**

I. Introduction

The increasing market of mobile devices and mobile services, continuous development and diversification of user terminals as well as availability of various wireless network technologies challenge resource limitations of wireless access networks. This requires consideration of the resource allocation problem from the different angle, including collaboration between mobile users and networks in improvement of the utilization of resources. Referring to wireless access networks, the ability to be connected to several network technologies poses new challenges in formulating effective strategies for selecting the best network. The network selection problem inspired by the "always best connected" concept was mostly focused on the definition of metrics to address the end user quality of service and considered the problem from a single user view point.

Multicast [1] is an efficient method for point-to-multipoint communications, which reduces drastically the usage of network resources when the same content is sent to a large group of users. Different types of applications like video conferencing, file distribution, live multimedia streaming can benefit from deploying multicast networking. However, the well-known complexity of managing multicast networks makes the deployment of multicast even more challenging in wireless environments when mobility issues have to be considered. In this paper, we consider a solution for the network selection problem for heterogeneous mobile networking as a part of multicast group management.

The remainder of the paper is organized as follows. After presenting an overview of related work in Section II, we discuss a representative scenario in Section III. We present the problem formulation and outline a suitable algorithm in Section IV. A usage example and test results are given in Section V, before discussing future work and concluding in Section VI and Section VII, respectively.

II. Related Work

To the best of our knowledge, the research field concerning selection of a network in heterogeneous wireless networks from a perspective of multicast delivery is not well exploited. Most previous works for mobile multicast focus on optimal multicast tree construction in multihop ad hoc networks [2–5].

Ormond and Murphy [6] propose a network selection approach that uses a number of possible utility functions. This solution is user-centric, and an interplay between different users and networks is not considered; neither is a multicast scenario. Ormond and Murphy conclude that the impact of multiple users operating in the same region needs to be further examined.

Gluhak et al. [7] consider the problem of selecting the optimal bearer paths for multicast services with groups of heterogeneous receivers. The proposed algorithm selects the bearer path based on different optimization goals. However, Gluhak et al. address the problem only for the ideal static multicast case without taking into account users crossing different cells. In their work, multicast membership does not change during the duration of a service, and multicast groups are not built with consideration of users' movements. In our opinion, this is not a realistic case for wireless networks.

Yang and Chen [8] propose a bandwidth-efficient multicast algorithm for heterogeneous wireless networks that is formulated as an Integer Linear Programming problem that is solved using Lagrangian relaxation [9]. The algorithm deals only with constructing optimal shortest path trees for multicast groups. In this approach, important parameters such as cost of service, user's velocity, etc. are not considered.

Jang et al. [10] present a mechanism for efficient network resource usage in a mobile multicast scenario. This mechanism is developed for heterogeneous networks and implements network selection based on network and terminal characteristics and Quality of Service (QoS). However, in the proposed mechanism, the network selection is performed purely based on terminal's preferences, the network perspective is not considered, and the solution does not optimize the utilization of network resources.

 ISBN: 978-1-61208-231-8

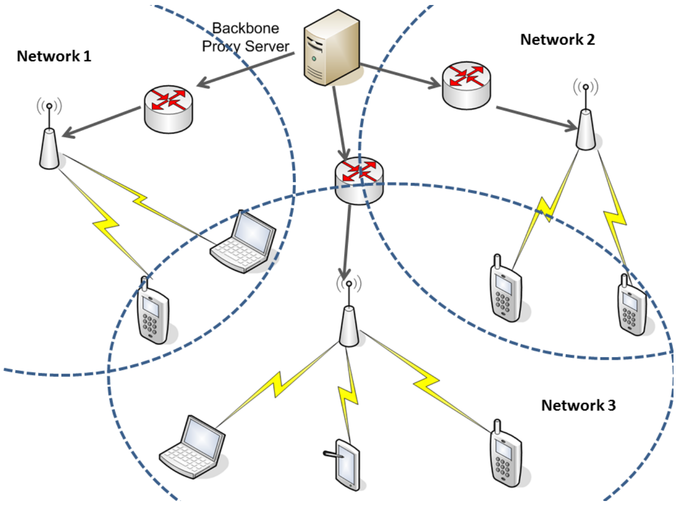

Figure 1. Multicast streaming scenario for a group of mobile clients served by several mobile networks before regrouping.

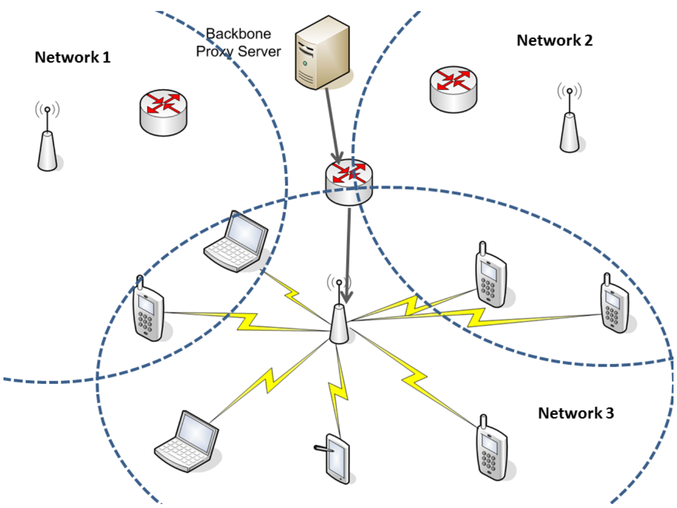

Figure 2. Multicast streaming scenario for a group of mobile clients switched to one mobile network after regrouping.

In our analysis, we recognize that the presented previous work has not addressed several important aspects related to the network selection for mobile multicast groups. We need to study how the users' movements influence the optimal selection of members for multicast groups and how the information needed for network selection is exchanged between the decision makers.

III. Scenario

To illustrate the yet unsolved challenges for optimal network selection in multicast networks, we consider a multimedia streaming scenario for a group of mobile users that concurrently receive the same content from the Internet. We assume that a backbone proxy server (BPS) is placed at the network edge. The BPS is a member of a content distribution system (CDN). This scenario is an extension of a scenario that we previously have considered to illustrate an adaptive multimedia streaming architecture to mobile nodes [11].

The BPS streams content that either is hosted on the server, or resends the streaming content as a part of an application layer multicast. The users of this network are located in an area with a substantial overlap in coverage of several mobile networks, and are connected to different networks. The base stations of the system have multicast capabilities, implementing, for example, Multimedia Broadcast Multicast Service [12]. A representative scenario of such networking is illustrated in Figure 1.

In our scenario, the mobile terminals are capable to connect to several access networks, and vertical handoffs between these networks are technically possible. Further, we assume that these terminals are equipped with GPS receivers, so that their location information can be transmitted to the BPS. The BPS can use this information to determine how the users can be regrouped in multicast groups. Such regrouping is beneficial as it saves network resources. Hence, the users that get the same content can exploit the same wireless link because the content can be broadcasted to them. The resources in the backhaul network are also better utilized because the content is now delivered only to one mobile network instead of being spread to several networks. An example of such regrouping is depicted in Figure 2.

Technically, to facilitate such a mechanism, the user terminals will have the possibility to switch to other mobile networks after receiving certain messages from the BPS. Since users may have different preferences depending on diverse criteria, for example, power consumption, security, network cost of service, etc., the interplay between the users' utilities and the networks' utilities is important to consider. In the current paper, we formulate and solve the problem, which solution gives us an optimal allocation of mobile users to mobile networks.

IV. Problem Formulation

In this section, we formalize the scenario discussed in Section III.

We consider a set of networks $N = 1, 2, \ldots, n$, a set of mobile nodes $M = 1, 2, \ldots, m$ and a set of streaming contents $S = 1, 2, \ldots, s$. Each content s_k can be delivered to more than one mobile node m_j. Therefore, using multicast for data dissemination is beneficial. For each node m_j and network n_i, the following is defined: available bandwidths of networks are denoted by b_i; streaming bitrate requirements of mobile nodes that request content s_k are denoted by r_k; $rss_{i,j}$ is the received signal strength in network n_i for terminal m_j, while power consumption and the cost of service in network n_i for node m_j are denoted by $p_{i,j}$ and $c_{i,j}$, respectively.

For each node m_j, we define a user preference profile that is described by a tuple containing Th^p_j, Th^c_j, and Th^{rss}_j. These denote thresholds or user preferences, for, respectively, power consumption, cost of service and received signal strength.

For each node m_j and each mobile network n_i we define

 ISBN: 978-1-61208-231-8

an availability function δ as follows:

$$\delta(i,j) = \begin{cases} 1, \text{if } n_i \text{ is available for } m_j \\ 0, \text{if not} \end{cases} \quad (1)$$

For each mobile network n_i and each streaming content s_k we define a function γ as follows:

$$\gamma(i,k) = \begin{cases} 1, \text{if at least one } m_j \text{ receives } s_k \text{ in } n_i \\ 0, \text{if not} \end{cases} \quad (2)$$

We define a decision variable $x_{i,j}$ as follows:

$$x(i,j) = \begin{cases} 1, \text{if } n_i \text{ is assigned for } m_j \\ 0, \text{if not} \end{cases} \quad (3)$$

To find the best possible allocation of the mobile nodes to the available networks in terms of minimization of consumed bandwidth, we minimize the following objective function:

$$\min \sum_{n_i \in N} \sum_{s_k \in S} \gamma(i,k) \cdot r_k \quad (4)$$

The objective function is subject to the set of constraints given below.

We need to garantee that each mobile node is assigned to one network.

$$\forall \{i\} : \sum_j \delta_{i,j} \cdot x_{i,j} = 1 \quad (5)$$

We need to specify that user preferences defined in their profiles are satisfied.

$$\forall \{i,j\} : x_{i,j} \cdot p_{i,j} \leq Th_j^p \quad (6)$$

$$\forall \{i,j\} : x_{i,j} \cdot c_{i,j} \leq Th_j^c \quad (7)$$

$$\forall \{i,j\} : x_{i,j} \cdot rss_{i,j} \geq Th^r ss_j \quad (8)$$

The defined problem is a typical integer linear programming problem. To solve this problem we have taken advantage of the MATLAB Optimization Toolbox. We use the function *bintprog*, which solves problems of the following form

$$\min_x f^T x \text{ such that } \begin{cases} \mathbf{A} \cdot x \leq b, \\ \mathbf{A_{eq}} \cdot x = b_{\text{eq}}, \\ x \text{ binary.} \end{cases} \quad (9)$$

V. Usage Example

The system computes the optimal assignment of mobile nodes to networks for a given static network condition and application situation. It is not a topic of this paper to compare any existing network selection algorithms with this system, but we consider it necessary to demonstrate that the optimal network selection decision does not have a trivial solution in the general case. We have done this by applying the computation to several network topologies. Here, we show the examples.

Table I
Total consumed bandwidth of the system.

Number of networks	Random	Optimum
4	26144	8072
5	32680	7560
6	39216	6536

We consider a scenario with four, five and six wireless networks and 1000 mobile users in the system. Not all of these networks are simultaneously available for all users. We consider two local WLANs that do not cover the whole area in consideration and, therefore, not all users have the access to these networks. 25% of users can access both WLANs, 50% can access one of them *equally distributed*, and 25% can access none of the WLANs. The rest of the networks deploy 4G LTE technology. Further, we divide the requested content into four categories in terms of required bandwidth, 512 kbps, 1024 kbps, 2000 kbps, and 3000 kbps.

In this experiment, we evaluate the total consumed bandwidth for all networks. The results for the total bandwidth in kbps are shown in Table I. We see clearly that the system achieves a much higher throughput than the random network selection approach.

VI. Discussion

The implementation of the algorithm in real systems requires that all knowledge of network resources and preference profiles of users is available to the BPS or some other central unit that decides upon how the data transmission shall be constructed. This implies that a significant number of messages needs to be exchanged inside the system, which comes at the cost of increased delays, need for network resources, and computation resources on mobile devices. To overcome this problem, we need an algorithm that is designed to handle the aforementioned information uncertainty. Several research studies address combinatorial problems that contain input data, which cannot be obtained accurately [13–15]. The problem discussed in Section IV will be reformulated using the results of these studies. This requires that the thresholds in the constraints 6, 7, and 8 are replaced with probabilities for these preferences.

VII. Conclusion

The paper studied the problem of selecting the optimal network for multicast groups of mobile clients in multi-stream scenario based on mobile clients' preferences and location information. We proposed a method that provides the optimal assignment for a given network topology, network conditions and user preferences.

Since the calculation is rather computing-intensive, and since the knowledge of the entire system state is necessary for the calculation, we conclude that this method is not suited for large scale networks due to scalability reasons. However, the method can be used for small scale networks and, mostly important, we intend to use the method as a reference to evaluate related algorithms that allow network selection in a decentralized manner with only limited information shared among the decision makers.

As a further step, we intend to develop distributed algorithms that operate under partial knowledge of the network topology and conditions, inaccurate knowledge of clients' preferences, dynamically changing networking parameters such as available bandwidth of mobile networks and network availability for mobile nodes.

VIII. Acknowledgment

The work described in this paper has been conducted as a part of the ADIMUS (Adaptive Internet Multimedia Streaming) project, which is funded by the NORDUnet-3 programme.

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