Q-learning based Wi-Fi Direct Grouping Algorithm considering Optical Backhaul

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Abstract

To mitigate backhaul-based traffic congestion and improve their latency performance, device-to-device (D2D) communications via Wi-Fi Direct, we propose a novel Wi-Fi Direct grouping algorithm with the assistance of the optical backhaul networks and optimize its performance by using Q-learning schemes under the consideration of multiple groups. The proposed algorithm is evaluated by means of extensive simulations, comparing its performance with conventional Wi-Fi offloading in terms of average completion time of (video) file transfers.

1. Introduction

An increasing amount of popular multimedia content, e.g., music videos, has been downloaded by large numbers of users for entertainment. YouTube experiences more than 6 billion video viewings per month [1]. Interestingly, the vast majority of video traffic is caused by a few popular files though [2]. Thus, if mobile users in proximity of each other share these files via a device-to-device (D2D) link instead of downloading the video again from the backbone server, the massive traffic congestion of cellular networks can be reduced significantly. D2D communications represents a promising means to resolve the capacity issues of optical backhaul infrastructures [3].

Wi-Fi Direct is a simple and commercially already available D2D technology, which operates on unlicensed (instead of expensive cellular) frequency bands at lower power consumption levels and data rates generally higher than cellular links [4]. Wi-Fi Direct inherits all benefits of IEEE 802.11, including high data rate service, enhanced quality of service (QoS), and security [5]. In a typical Wi-Fi Direct setting, a device performs either as an access point (AP), referred to as the so-called Group Owner (GO), or as a client. Each of these roles involves a different set of functionalities. In Wi-Fi Direct, these roles can be assigned dynamically, and hence a device may carry out both the role of a client and an AP. In this paper, we propose and investigate an efficient D2D link management strategy for multiple Wi-Fi Direct groups by exploiting Q-learning technique. In our architecture, each eNB and AP is served by a dedicated ONU to interface with the optical fiber backhaul. We refer to these integrated eNB-ONU and AP-ONU units henceforth as eNB/ONU and AP/ONU, respectively. D2D communications is achieved by the use of Wi-Fi Direct.

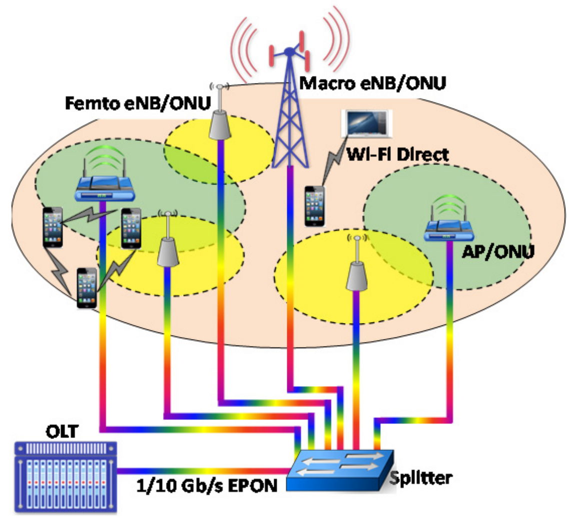

Figure 1. Network architecture.

2. Network Architecture

Figure 1 illustrates the network architecture of integrating the wireless systems with support of D2D communications and optical backhaul. The backhaul fiber network is realized by using a conventional Ethernet passive optical network (EPON). A subset of optical network units (ONUs) is located at the premises of residential or business subscribers, whereby each ONU provides fiber-to-the-home/business (FTTH/B) services. In the wireless front-end network, a macrocell evolved Node B (eNB) is used and femtocell eNBs and APs are randomly deployed, whereby their coverage areas may overlap with each other.

3. Q-Learning based Wi-Fi Direct Grouping

The proposed grouping algorithm is able to adapt itself to the current network environment by taking previous knowledge into account and act proactively, rather than reactively, in order to avoid low performance before it happens. This adaptation is achieved by continuously evolving and enhancing the applied adaptation strategies obtained from previous actions. Grouping is closely related to an autonomic mechanism, which makes decisions through the use of learning mechanisms, taking advantage from previous experiences in order to perform optimally in the future. Therefore, the grouping algorithm can be viewed as a dynamic optimization problem embedded in a stochastic environment, whereby Q-learning is one of the effective ways to find a solution to this problem.

Given that a significant amount of video traffic is delivered via wireless networks, Wi-Fi Direct can be applied to enable efficient sharing of video content between users and thereby release the traffic burden on cellular BSs. In such a scenario, a network-assistant procedure is necessary to determine whether the requested content is available at other users. More precisely, eNB/ONUs and AP/ONUs need to maintain lists about downloaded content for their respective cells. When a listed video is requested by a mobile user, eNB/ONUs and AP/ONUs help build a D2D connection between the requesting user and the user having a copy of the video.

Note that the above simple scenario can be generalized to multiple Wi-Fi Direct groups with numerous co-existent GOs. In this case, the presence of multiple clients and GOs in a cell renders the group formation problem more involved with a larger impact on the network performance. Clearly, to achieve the maximum advantages in a multiple Wi-Fi Direct group setting, an optimal grouping operation is needed. Towards this end, in our proposed grouping algorithm, eNB/ONUs and AP/ONUs control a set of Wi-Fi Direct groups and act as an agent with learning capability. They are in charge of recognizing the current environmental state, selecting the action based on Q-learning, and exploiting it.

4. Results

We evaluate the performance of our proposed Wi-Fi Direct grouping algorithm considering optical backhaul by means of extensive simulations. The network consists of one macro eNB/ONU, 16 femto eNB/ONUs, and 15 AP/ONUs, which are randomly distributed across the coverage area of the macro eNB. We assume a maximum distance of 3 km between any pair of adjacent eNB/ONUs and AP/ONUs, which is well within the maximum cell coverage area of presently available macro eNBs. Multiple Wi-Fi Direct groups are established, whereby all Wi-Fi Direct devices are based on IEEE 802.11n high-throughput WLAN technology.

Fig. 2 depicts the file transfer time versus the number of clients in the network requesting specific video files. We measured the average completion time for the file transfer of two videos with different size, 30 Mbytes and 100 Mbytes. We observe from Fig. 2 that the Wi-Fi Direct based file transfer is able to achieve a significantly reduced delay. For the 100 Mbyte file transfer, the file transfer time of 250 s obtained with Wi-Fi Direct exhibits a performance improvement of 160% compared to conventional Wi-Fi transmission, which remains at around 650 s in the case of 500 clients. For the case of 30 Mbyte video file transmissions, an increase in file transfer time up to 200 s is observed for the largest number of clients for Wi-Fi, while the completion time of Wi-Fi Direct is as low as 200 s. These performance differences are due to the fact that conventional Wi-Fi transmission involves additional overhead procedures, as opposed to Wi-Fi Direct. Specifically, control signaling overhead between the video server and AP takes place via the backhaul network before the server delivers the requested video file to the requesting UEs. In addition, packets coming from the video server have to be routed end-to-end across network components until they arrive at the destination. When the file is trans-mitted to the UEs, it is controlled by the downstream scheduling mechanism in the OLT, generally competing with other downstream traffic. In contrast, the file delivery between GOs and clients via Wi-Fi Direct does not involve the above overhead procedures. GOs and clients only have to perform the group formation setup among them with the assistance of the FiWi network. As a result, D2D links help reduce file transfer times significantly as well as decrease processing time.

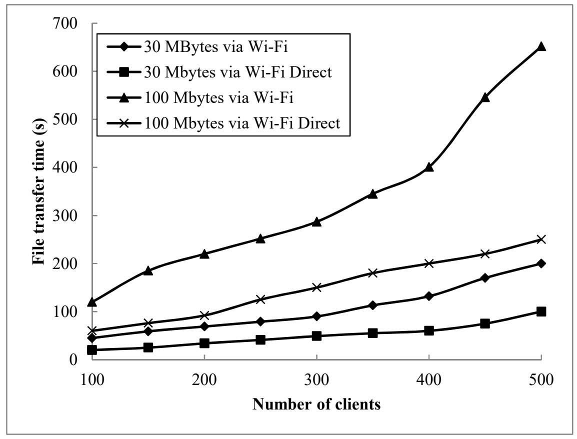

Figure 2. Comparison of file transfer time between Wi-Fi and Wi-Fi Direct for 30 Mbyte and 100 Mbyte files.

5. Conclusions

To deal with ever-increasing bandwidth demands raised by the increasing adoption of bandwidth-hungry mobile users, we introduced the optical and wireless converged access networks based on complementary EPON and cellular infrastructures in support of D2D communications via Wi-Fi Direct. We then proposed a Q-learning based Wi-Fi Direct grouping algorithm, taking multiple groups and network assistance into account. The performance of data transmissions via D2D links was compared to that of conventional Wi-Fi offloading. The obtained results show that the file transfer time via Wi-Fi Direct provides a 160% improvement over Wi-Fi offloading for 100 Mbyte file delivery among 500 clients.

6. Acknowledgements

This research was supported by Research Fund, Kumoh National Institute of Technology and the MSIP(Ministry of Science, ICT and Future Planning), Korea, under the ITRC(Information Technology Research Center) support program(IITP-2017-2014-0-00639) supervised by the IITP(Institute for Information & communications Technology Promotion)

7. References

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