A Channel Selection Method for Device to Device (D2D) Communication Using the Mobile Edge Computing (MEC) Paradigm

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Abstract. Nowadays, LTE (Long Term Evolution) had been developed stably and can support large scale communication services to mobile devices, the traffic offloading in core network and mobile devices is still an issue. Besides, the intensive collision between mobile devices is also an issue because they need to compete the finite network resources with each other. Mobile Edge Computing (MEC) is a promising technique applied to network edge, which can assist the edge device to offload the data traffic and decrease the gigantic computation effort through sending the complicated tasks to remote MEC before sending to core network. To solve the traffic and location issues, this paper proposed a channel selection scheme for MEC-assisted Device to Device Communication Offloading (MD2DO) which can help the peered mobile devices to confirm the location of the mobile device and efficiently have Wi-Fi D2D through channel selection for traffic offloading.

Keywords: Mobile edge computing (MEC) · Device to device communication (D2D) · Channel selection · Offloading

1 Introduction

LTE cellular network can provide large-scale communication services and support users to access network ubiquitously. With the high increase rate of mobile users, it always has heavy loading and congestion in cellular network. To tackle the aforementioned problems of cellular network, many methods and studies of offloading cellular network traffic were proposed and discussed, such as Wi-Fi offloading [1, 2] and Device to Device Communication (D2D) [3, 4]. With the techniques of Wi-Fi offloading and D2D communication, mobile devices can utilize other communication way's available bandwidth to relieve the heavy load in cellular network.

Current Wi-Fi offloading has the mobile device to switch from attaching with a Base Station (BS) of cellular network to attaching with an AP of the Wi-Fi network when a Wi-Fi AP is available and vice versa when the Wi-Fi AP is unavailable. Thus, it

J.-L. Chen et al. (Eds.): WiCON 2018, LNICST 264, pp. 173–182, 2019.
https://doi.org/10.1007/978-3-030-06158-6_18

belongs to the infrastructure-based approach. When a mobile device switches from cellular network to Wi-Fi network or from Wi-Fi network to cellular network, it needs to have some signal transmission for automatic switch or some manual operation from the corresponding user. To have the signal transmission and control for automatic switch between Wi-Fi network and cellular network, 3GPP of the International Telecommunication Union (ITU) devised the standard of LTE WLAN Aggregation (LWA) [5]. Using LWA, Mobile Network Operators (MNOs) can adjust the usage ratio of LTE and Wi-Fi according to the using status of the mobile devices for downloading data; but, users can only use LTE for uploading. Thus, the LWA technique has the potential of increasing network utilization and system capacity and the peak throughput users can experience.

The other offloading method technique is based on D2D communication, which belongs to the un-infrastructure communication way. D2D communication allows direct communication between proximate mobile devices to reduce the load of the core network. LTE D2D [6] and Wi-Fi D2D [7] are two well-known D2D communication techniques, which can offload the infrastructure-based traffic of cellular network. LTE D2D has advantages of larger signal coverage, fast device discovery and high privacy. But LTE D2D utilizes licensed bandwidth of LTE cellular network and therefore it may not be free. In contrast, Wi-Fi D2D can enable quick connection and direct communication of two mobile devices using the unlicensed band. That is, Wi-Fi D2D utilizes unlicensed band and thus can offload cellular network's traffic more effectively.

MEC is a new computing paradigm that can provide cloud computing in network edge to meet some real time requirements [8, 9]. MEC is considered as a key enabler to help resource-limited mobile devices to process gigantic volume of data before sending these data to the core network, support delay-sensitive applications and services and remedy high bandwidth requirement of current cellular network. The deployment of a MEC server is expected to be placed at the edge of mobile network, e.g. each eNB is associated with an MEC server that plays the role of a centralized manager and offers high virtualized computation and storage. The MEC technique not only improves the edge network utilization but also alleviates cellular traffic. Thus, instead of using the remote cloud server, mobile devices can have the heavy tasks that need complicated calculation, e.g., collect edge network information, to the near powerful MEC server for saving cellular traffic.

When the peered mobile devices are communicating with each other using the cellular network, each mobile node's Wi-Fi interface switches to each Wi-Fi channel periodically. Let each mobile node report its context, which contains the sensed Wi-Fi APs in each Wi-Fi channel, to the MEC server periodically. When the MEC server finds that the peered mobile devices sensed the same Wi-Fi AP in a specific channel m, for which they did not switch to the same channel to sense at the same time, it implies that the peered mobile devices are proximate with each other. Thus, the MEC server notifies these two peered mobile devices to go to channel n, which has the better networking situation calculated by the MEC server, to try Wi-Fi D2D offloading in channel n. Although there are researches exploring how to apply MEC for the access technologies of network, researches of applying MEC to measure channel quality and have Wi-Fi D2D offloading are still insufficient.

The rest of this thesis are organized as follows. Section 2 presents related works, including D2D communication, LWA, MEC and traffic offloading. Section 3 presents details of the proposed MD2DO method. Section 5 presents performance analysis. Finally, Sect. 6 summarizes and has conclusion remarks.

2 Related Work

LTE-WLAN aggregation (LWA) is a standard made by International Telecommunication Union (ITU) [5, 10]. Through the integration of LTE mobile network and Wi-Fi wireless network, mobile devices can simultaneously access two kinds of network services, for which uploading is through LTE and downloading is through either Wi-Fi or LTE. This communication paradigm solves the contention problem of wireless network and meanwhile efficiently performs downloading using both licensed band and unlicensed band. Comparing with the past technique, on which users have to manually switch between LTE and Wi-Fi to select the preferred network service, mobile network operators can provide appropriate services through the diagnosis of the network status that users are using and achieve network optimization based on LWA.

In [11], the authors proposed a Self-Organizing Network (SON) algorithm according to the network status, i.e., the quality of LTE communication link (SINR) and RSSI of wireless network (WLAN) of each user, to adjust the control parameter of the LWA transmission mode. The proposed SDN algorithm not only provides higher transmission rate but also guarantees better service quality, and thus enhances user satisfaction.

In [12], the authors adopted a new comprehensive optimization framework to solve the increasing demand of downloading large data on cellular network. Using the proposed method, a base station sends different chunks of contents to a group of Mobile Devices (MD), and then some MDs multicast these chunks to other MDs in the same group using D2D. The framework optimizes the chunk distribution and multi-hop cooperation while keeping the fairness constrains on the power consumption of the MDs and multicast transmission. The optimization problem is a NP-complete problem. The authors obtained computationally fast solutions with the close-to-optimal performance using the polynomial time greedy method.

In [13], the authors proposed a dynamic channel assignment method based on a regret learning algorithm (DCA-LA), which takes co-channel interference (CCI) power, the average CCI power estimation and the utility estimation into account, for base stations (BSs). In the algorithm, BSs learn nearby BSs' channels by altering their channels and minimizing their regrets if they do not select other available channels. A BS distributes a non-zero probability to each channel and the higher probability is assigned to one with more regret. In this way, it can decrease the chance of two adjacent cells selecting the same channel. The algorithm is processed in a fully distributed manner, therefore, it does not need to exchange signal information between BSs.

3 The Proposed Scheme- MD2DO Method

In this section, the control flow of the proposed MD2DO scheme, for which phase 1 is D2D Peer Discovery and Channel Selection and phase 2 is Association and Offloading, is presented in detail.

A. The Control Flow
Initially, each mobile node that is using cellular network reports its context, including the collected network information, to the MEC server periodically using cellular network. The MEC server uses the contexts sent by mobile devices to coordinate the infrastructure communication using cellular network and the Wi-Fi D2D communication using Wi-Fi network. Let mobile devices MN1 and MN2 be communicating with each other using cellular network. When the MEC server finds that mobile devices MN1 and MN2 can receive the beacon sent by the same AP in the same Wi-Fi channel, it indicates that MN1 and MN2 are proximate with each other because they are in the signal coverage of the same Wi-Fi AP. When the MEC server confirms MN1 and MN2 are proximate with each other, the MEC server calculates each Wi-Fi channel's quality according to the networking information sent from Wi-Fi AP and mobile devices and then assigns the better Wi-Fi channel for MN1 and MN2 to try Wi-Fi D2D communication; otherwise, MN1 and MN2 keep using cellular network.

B. D2D Peer Discovery and Channel Selection
When two mobile devices are proximate with each other, having Wi-Fi D2D communication can further improve the performance of the network and reduce the burden of cellular network and even Wi-Fi APs. The first issue to have Wi-Fi D2D communication is to confirm the location of mobile devices because mobile devices keep moving. In this paper, each mobile device, which is using cellular network, uses the collected network information to make a Carrier Sense Information (CSI) record, which includes current time, MAC addresses of nearby mobile devices, i.e., the ones that the mobile device can sense, MAC address of nearby Wi-Fi APs, sensed RSSI of nearby mobile devices, and its own Frame Error Rate (FER), Contention Window (CW) Size, and sends it to the MEC server to judge the networking situation.

Each mobile device would utilize passive scanning for listening to beacon frames in each Wi-Fi channel because passive scanning does not require any signal transmission from the mobile device, i.e., it is an action of passively receiving and thus the mobile device can save power. A mobile device would switch from one Wi-Fi channel to the other Wi-Fi channel and wait for the beacon frames sent from Wi-Fi APs that are using the corresponding channel currently.

In this paper, in addition to have passively scanning, i.e. receiving beacon frames sent by Wi-Fi APs to know the MAC addresses of Wi-Fi APs, each mobile device would overhear the received data packets, which are sent by surrounding mobile devices, to record related data, i.e., MAC addresses of nearby mobile devices and sensed RSSI of nearby mobile devices. Besides the aforementioned data, each mobile device measures its own FER and CW to compose the CSI (Carrier Sense Information) record. The MEC server estimates the channel quality of each Wi-Fi channel and selects the best one for peered mobile devices to try to have Wi-Fi D2D communication using the *Channel Selection algorithm*, which will be presented in the next section.

C. Association and Offloading

After the calculation of channel quality and the selection of a suitable Wi-Fi channel, the MEC server notifies the peered mobile devices to start the association process in the assigned channel. The association process is used to confirm that the peered mobile device MN1/MN2 is in MN2's/MN1's Wi-Fi signal coverage and can communicate with each other directly using Wi-Fi D2D communication in the assigned channel. If the association is successful, then the peered mobile devices can have Wi-Fi D2D communication. When Wi-Fi D2D communication ends, MN1 and MN2 switch to the cellular network to continue scanning and reporting. However, if the association process is failed, the peered mobile devices MN1 and MN2 keep using the cellular network to communicate with each other and send the failed result to the MEC server.

4 The Functional Scenario of the Proposed MD2DO Scheme

The aforementioned problem can be resolved using the MEC paradigm. Let (1) each mobile device report its CSI record, which contains MAC addresses of nearby mobile devices, MAC address of nearby Wi-Fi APs, the sensed RSSI of nearby mobile devices, and its own Frame Error Rate (FER) and its own Contention Window (CW) Size, and (2) each Wi-Fi AP report its context, which contains its FER and CW, to the MEC server. The MEC server can analyze each channel's situation based on the aforementioned contexts reported from mobile devices and Wi-Fi APs.

1. The MEC server creates *ChannelQualityList*.
2. **for** each channel k, k = 1, 6, 11,
3. Calculate the channel quality for x (C_x^k) and y (C_y^k) at channel k.
4. Add $min\{C_x^k, C_y^k\}$ to *ChannelQualityList[k]*.
5. end **for**
6. The MEC server selects channel m that has the maximal channel quality value $\boldsymbol{Q^m}$ among all *ChannelQualityList[k]*, k = 1, 6, 11, as the suitable channel for Wi-Fi D2D communication.
7. MEC server notifies the peered mobile devices x and y to use the Wi-Fi channel to try Wi-Fi D2D communication.

Let mobile devices x and y be the peered mobile devices that have the chance to try Wi-Fi D2D communication. Two part of the *Channel Selection algorithm*, are (1) channel quality calculation, which calculates the quality of each channel based on the reported CSI records of mobile devices and the reported contexts of Wi-Fi APs and (2) channel selection, which chooses the suitable channel that will be assigned to the peered mobile devices for having Wi-Fi D2D communication. The formula for channel quality calculation is as follows:

$$\text{Channel Quality} = \frac{1}{\emptyset}, where\emptyset = \left[\frac{\sum_{i=1}^{N} \left(FER_i \times CW_i \times \left| \frac{1}{RSSI_i} \right| \right)}{N} \right]$$

N is the number of nearby mobile devices that are sensed by each one of the peered mobile devices in the corresponding channel. That is, the bigger/smaller *N* is, the more/less mobile devices there are in the corresponding channel could be influenced. FER indicates the frame error ratio, which is equal to the number of retransmission times is dividing by the number of total transmission times in each mobile device. The value indicates the probability of unsuccessfully transmitting packets and can be used to indicate the channel networking situation. Each mobile device, which connects to the Wi-Fi AP or Wi-Fi D2D communication, needs to calculate its *FER* value after sending a packet and then reports the *FER* value to the MEC server. The value of *CW* indicates the average contention window size of all of the transmitted packets' contention window size and is used to imply the delay time of accessing a channel. Each mobile device, which has connected to the Wi-Fi AP or Wi-Fi D2D, needs to report its *CW* value to the MEC server periodically for measuring the delay time of accessing the channel. After a mobile device scans all of the Wi-Fi channels and needs to report, it calculates how many packets the mobile device has been sent since the most recent report, and then calculates a new *CW* value to report. *RSSI* is an indicator to measure the intensity of received energy of mobile devices. Through this measurement, the distance between the receiving end and the transmitting end can be inferred.

The higher the RSSI value is, (1) the stronger the energy of the received signal is and (2) the shorter the distance between the receiving end and the transmitting end is, meanwhile, the mutual influence of these two neighboring entities, i.e., the receiving end and the transmitting end is stronger. To select a channel with less influence, it can calculate the absolute value of *RSSI* and finds the inverse of the calculated number as an index. The lower the value is, the longer the distance between the receiving end and the transmitting end is and the influence between neighboring devices is weaker.

After calculating all channels quality's value, these channels will be separated into two exclusive groups. If the channel that the peered mobile devices sensed has no nearby mobile devices, the channel will be classified to the first group; otherwise, the channel will be classified to the second group. Then, the MEC server selects the channel from the first group because the channel in the first group have no node and thus the channel quality is the best.

5 Performance Analysis

This section presents the performance analysis and simulation results for the proposed scheme. The configured parameters that are used in the simulation are listed in Table 1. To present the results in a more comprehensive way, the simulation is divided into two parts, in which one is associated with eleven Wi-Fi channels, i.e., channel $1 \sim 11$, and the other one is associated with three Wi-Fi channels, i.e., channel 1, 6 and 11.

Table 1. The parameters used in the experiment.

Simulation parameters	Value
MAC protocol	802.11 g
Propagation model	Two ray
Slot time	9 μsec
SIFS time	10 μsec
PIFS time	19 μsec
DIFS time	28 μsec
Packet size	1024 byte
ACK size	14 byte
Queue length	1024 packets
Min. contention windows	32
Max. contention windows	1024

To explain the channel's networking situation conveniently, two terminologies are defined as follows:

- ***Good channel***: If the channel is called a good channel, wherein two mobile nodes have Infrastructure-based Wi-Fi communication using the channel for transmitting data, the collision is less and channel loading is low.
- ***Bad channel***: If the channel is called a bad channel, wherein thirty mobile nodes have Infrastructure-based Wi-Fi communication using the channel for transmitting data, and the collision in is critical and the channel's loading is high.

To verify that the mobile nodes using the proposed the MD2DO can have Wi-Fi D2D using good channels and always achieve higher network performance when the number of new arrival nodes increases, two networking situations are discussed. In case A, channel 6 and 11 are good channels and channel 1 is a bad channel. In case B, to observe the node number, transmission rate and throughput of each channel in the simulation process, the environment setting are that channel 6 and 11 are good channel and channel 1 is a bad channel and the number of new arrival nodes is thirty-six.

5.1 The Performance Analysis

Case A: Channel 6 and 11 are good channels and channel 1is a bad channel
Figures 1(a) and 2(a) depict the transmission rate comparison of Case A with the increasing number of new arrival nodes. It can be observed that the trend of transmission rate of channel 6 and channel 11 gradually close to channel 1 using the MD2DO method. The reason is that new arrival nodes can use the better channels, which are selected by the MEC server, for having Wi-Fi D2D. When new arrival nodes enter into the network, the MEC server assigned the good channel (channel 6 and 11) to them for having efficient Wi-Fi D2D such that new arrival nodes can avoid using the bad channel to have Wi-Fi D2D. Since new arrival nodes that are having Wi-Fi D2D can use good channels, the trend of transmission rate of channel 1 maintains stable. In

the Normal D2D scheme, the trend of transmission rate of channel 6 and channel 11 does not gradually close to channel 1. The channel that two new arrival nodes, which are communicating with each other, used is the one that the same Wi-Fi AP they sensed is using. If the corresponding Wi-Fi channel that the Wi-Fi AP is using is a bad channel, then they have Wi-Fi D2D in a bad channel. Even if there were still other good channels to choose, they can not use because there is no channel selection mechanism. Therefore, the transmission rate of three channels decrease simultaneously, which results in the lower network performance. The same situation happened in the comparison of the throughput and collision rate. Referring to Figs. 1(b)(c) and 2(b)(c), since MD2DO can choose better channels for Wi-Fi D2D, it can balance the loading of channel 1, 6 and 11, and thus it can have higher average throughput and lower average collision rate in these three Wi-Fi channels.

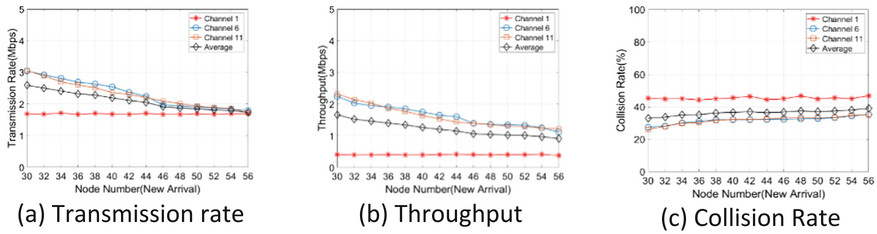
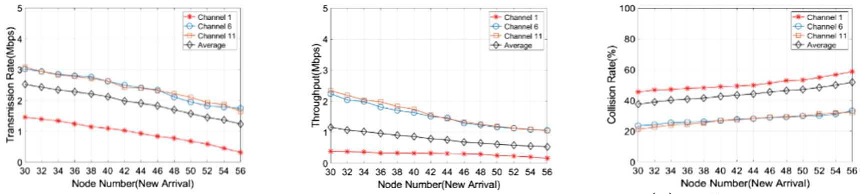


Fig. 1. The simulation results of using MD2D in case A.

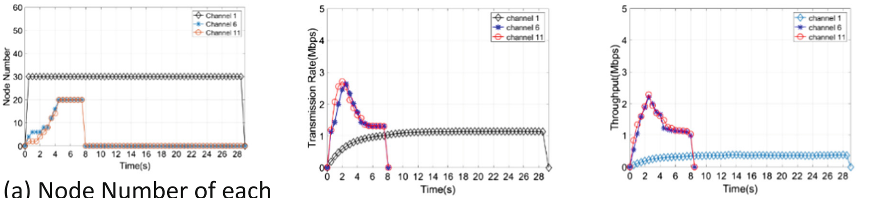
Case B: Channel 6 and 11 are good channels and channel 1 is bad channel
Figures 3(a) and 4(a) show the number of mobile nodes in each channel. In MD2DO, the number of mobile nodes in channel 1 is stable because the MD2DO method can let new arrival nodes use the better channel. Therefore, the number of the other two channels increases. In the normal D2D method, the number of mobile nodes in each channel is randomly increased. The reason is that no channel selection mechanism is used, i.e., new arrival mobile nodes used the channel that the same Wi-Fi AP both peered mobile nodes sensed is using. Thus, new arrival nodes were randomly scattered in these three channels.
Figure 3(b) and (c) depict the transmission rate and throughput of MD2DO. Initially, the transmission rate and throughput of channel 6 and 11 increase because new arrival node use channel 6 and 11 and avoid using channel 1 for having Wi-Fi D2D. Therefore, the transmission rate and throughput of channel 1 maintain stable. Figure 4 (b) and (c) depict the transmission rate and throughput of Normal D2D. Since new arrival nodes spread randomly in these three channels, transmission rate and throughput of these three channels varied. The transmission rate and throughput of channel 1 decrease because some new arrival nodes have Wi-Fi D2D using channel 1, which deteriorates the channel competition and results in lower network performance.

MD2DO can reduce the burden of bad channel and offload data traffic to good channels. Thus, MD2DO can enhance the channel utilization and shorten the simulation time. In this experiment, the proposed MD2DO improves about 15% simulation



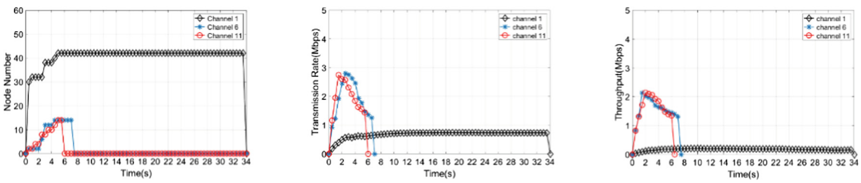
(a) Transmission rate (b) Throughput (c) Collision Rate

Fig. 2. The simulation result of using normal D2D in case A.



(a) Node Number of each channel in MD2DO (b) Transmission rate of each channel in MD2DO (c) Throughput of each channel in MD2DO

Fig. 3. The simulation results of using MD2D in case B.



(a) Node Number of each channel in Normal D2D (b) Transmission rate of each channel in Normal D2D (c) Throughput of each channel in Normal D2D

Fig. 4. The simulation result of normal D2D in case B.

time. However, the channel utilization is uneven using the Normal D2D, which may have new arrival nodes use the bad channels for having Wi-Fi D2D. Thus, the normal D2D exacerbates the network performance and prolongs the simulation time.

6 Conclusion

This paper proposed a scheme called MD2DO, which combines the MEC mechanism and Wi-Fi D2D to enhance the capacity of network and offload cellular traffic. The main concept of MD2DO is to have mobile nodes to collect the network information and send to the MEC server periodically to confirm the location of mobile nodes, calculate the channel quality and then assign the suitable channel for the peered mobile devices to have Wi-Fi D2D. Additionally, after the calculation of channel quality, the peered mobile nodes need to associate with each other in the assigned channel to confirm that they can communicate with each other directly. In this way, the mobile nodes have efficient Wi-Fi D2D using the channel that has the lower collision situation and thus it can balance the channels' loading. From the performance analysis, the proposed MD2DO has the higher network performance and the lower collision rate than normal D2D in different networking situations.

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