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Adaptive Packet Scheduling for Resource Interference Avoidance in LTE-Advanced Networks

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Abstract

Resource interference degrades the Quality of Service (QoS) in resource shared networks and this affects Device-to-Device (D2D) communications. This paper proposes an Adaptive Packet Scheduling Mechanism (APSM) to avoid resource interferences for (D2D) communication, which underlays Long-Term Evolution (LTE) networks. The proposed mechanism provides QoS-guaranteed service for D2D communications in all the three aspects of QoS, i.e. throughput, packet loss, and packet delay. The simulation results show that the proposed mechanism provides more efficient throughput compared to that of the regular cellular network.

Keywords: Cellular Network, Device-to-Device (D2D), Packet Scheduling, Resource Interference

1. Introduction

Recently, with a rapid growth of wireless networks, the demand for LTE-A networks is also increasing significantly. The Long Term Evolution-Advanced (LTE-A) networks are being developed to provide mobile broadband services for the Fourth Generation (4G) cellular wireless systems. D2D communications is a promising technique to provide wireless peer-to-peer services and reduce resource interference in LTE-A networks[1,2]. In general, D2D communications underlaying LTE-A networks provides the advantage for four types of gains[3–5]. The proximity of User Equipments (UEs) may allow for high bits, low delays and low power consumption. Secondly, the hop gain refers to using a single link in the D2D mode rather than using an uplink and a down link resource when communicating via the Base Station (BS) in the cellular network. Thirdly, the reuse gain implies that radio resources may be simultaneously used by cellular as well as D2D links. Finally, the pairing gain refers to the degree of freedom when selecting the UE that communicates communicating with the BS and the UE pairs using a direct D2D link that should use the same time and frequency resources[2,5]. As well, D2D communications may be supported new types of wireless peer-to-peer services and it provides efficiently the reuse for resources.

However, to guarantee efficient resource reuse in D2D communications, two major challenges of LTE-A networks should be considered. Firstly, the interference caused by packet congestions under D2D communications could significantly affect the performances of cellular devices. Secondly, the Quality of Service (QoS) requirements such as the enhancement for throughput should be guaranteed.

To satisfy these requirements, Lee et al.[3] proposed a TRM mechanism that improves the overall throughput in the network underlaying wireless communications to enhance the performance compared to the mechanism in which all D2D traffic is transmitted through the cellular link. Doppler et al.[6] suggested a D2D session connectivity mechanism based on Session Initiation Protocol (SIP) to detect potential traffics. In the session connectivity mechanism, sessions cooperates together with the packets to take care of the connectivity between the UEs and D2D link. However, these mechanisms do not resolve the continuous connectivity and resource interference avoidance caused by the link congestion toward the Evolved Node B (eNB).

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Therefore, this paper proposes a new Adaptive Packet Scheduling Mechanism (APSM) to reduce resources interferences for Device-to-Device (D2D) communication underlaying Long-Term Evolution (LTE) networks. Thus, the proposed APSM aims to guarantee a ceaseless packet transmission by considering Overload Check Bits (OCB) in the D2D link. The objective is to enhance the system throughput by considering the packet scheduling structure according to the Hybrid Automatic Repeat Request (HARQ) and link adaptation.

The rest of this paper is organized as follows. Section 2 introduces Related Works. Section 3 presents the proposed APSM mechanism for resource interference avoidance in the LTE-Advanced network, and Section 4 presents and discusses some simulation results. Finally, Section 5 draws conclusions.

2. Related Work

To maximize the throughput and QoS guarantee in the D2D communications, the modes of D2D devices should be considered as follows: Silent mode, reuse mode, dedicated mode, and cellular mode. These modes are the important components in determining the spectrum efficiency and traffic overload check. The system performance can be improved by the utilization and control of resources. However, these modes do not utilize the resources efficiently to maximize the overall throughput and QoS-guarantee. One of the main issues in D2D links is that they do not efficiently avoid the resource interference for D2D links so that the overall network throughput is maximized and the QoS of the communication links are guaranteed. Research has been conducted on various aspects to solve these problems.

Doppler[7] and Zulhasnine[8] suggested the mode selection problem for spectrum sharing between D2D links and cellular users in the network. This method only considers the received signal strength over a D2D link or the distance between the UEs. However, variations in UEs still affect the overall throughput of the D2D links.

Yu et al.[9] suggested a mode selection algorithm by considering the D2D and celluar link quality and the interference situation of each possible sharing mode. This method selects the mode that provides the highest sum rate while satisfying the Signal to Interference-Plus-Noise Ratio (SINR) constraint of the cellular network in both single cell and multiple cells. However, the algorithm did not apply the resource interference avoidance generated by adapting link congestion.

Belleschi[10] and Fodor[11] proposed a distributed resource allocation method to improve the scalability of D2D links. Their method aims to minimize the total power consumption under the constraints of sum rate and SINR.

Min et al.[12] proposed a new interference management scheme for advanced receivers to improve the reliability of D2D communications in the uplink without reducing the power of cellular UEs. This method has applied three receiving modes to improve the reliability of D2D links. However, this method does not control the desired interference as strong interference between UEs and D2D links.

Han et al.[2] proposed a resource allocation and beamforming algorithm based on interference avoidance. In this algorithm, D2D links and cellular links share the same radio resource and the management of interference. D2D communication enables new service opportunities, provides high throughput and reliable communication. However, this algorithm has the disadvantage of adaptive packet scheduling for UE with different D2D link environments.

3. An Adaptive Packet Scheduling Mechanism

Figure 1 is an adaptive packet scheduling structure to monitor the resource interference in the D2D link model. To detect whether resource interference is generated by a D2D communication link model, the model monitors the user request information and channel packets for data communication channel. The objective of the model is to reduce the load and improve the system throughput between UEs and eNB.

According to the packet scheduling structure of Figure 1, the D2D link model can be grouped into two categories: co-channel D2D and dedicated channel D2D. In the co-channel, the D2D link spectrum is the same as the operating spectrum that is consistent between the UE and the cell. It detects excessive packet explosion for cellular mobile systems and a data link and a control link plays an important role for spectrum monitoring when the user equipment has mobility. The packet scheduling process can be composed of four components: Hybrid Automatic Repeat Request (HARQ), link adaptation, overload detection for packet scheduling, and overload control based on Overload Check Bits (OCB).

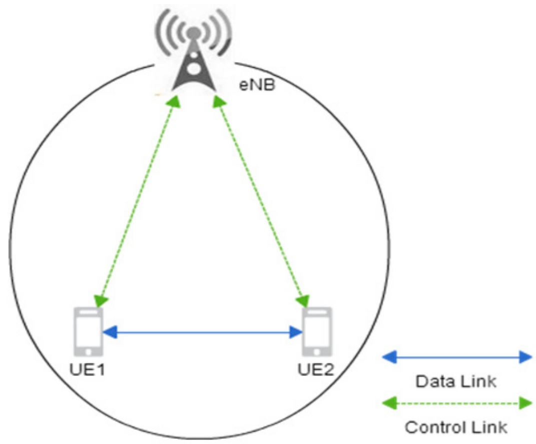

Figure 1. The proposed D2D link model.

3.1 HARQ

HARQ is an important error correction technique, and it is composed of Forward Error Correction (FEC) and ARQ. HARQ checks the explosion and congestion for the transmitted packets in the D2D link. This is achieved by adding overload check bits to the information bits prior to packet transmission. The OCB are calculated from the information bits using a method given by the scheduling structure used. Thus, the OCB over the channel monitors and checks the overload caused by packet explosion and congestion when the transmitted packets are greater than the number of original information bits and a certain amount of redundancy is greater than the link spectrum .

3.2 Link Adaptation

Link adaptation checks OCB for the system performance under the channel and spectrum conditions. When the LTE system considers OCB, it takes a throughput of UE_i at time t and the throughput decision TD_T for UE_i can be defined as follows:

$$TD_T = \frac{\sum_{i=1}^{n} DL(i) + \sum_{j=1}^{m} CL(j)}{\sum_{k=1}^{l} PT(k)} \tag{1}$$

Where $DL(i)$ is the data link rate for UE_i , $CL(i)$ is the link control rate from eNB to UE_i, and $PT(k)$ is the packet transmission rate from eNB to UE_i.

The performance of the system depends on the co-channel interference caused by the devices. Therefore, the co-channel interference for UE_i over the D2D link model can be defined as follows:

$$CI(i) = \sum_{i \in D} \left\| \sum_{i \in L_i} L_{error}(U_i) + OCB(i) \right\| \tag{2}$$

Where L_{error} is the link spectrum error for UE_i in the D2D link model.

3.3 Overload Detection for Packet Scheduling

In Figure 1, consider the packet scheduling between UEs and eNB, PS_{mn} , $m, n \in \{0,\ldots,M(t)\}$ and $m \neq n$. Moreover, a forward path and backward path are considered to detect the packet overload over the D2D link. As in Figure 1, each item of UE includes one forward path and a backward path with a random delay bit error. The forward path is defined as the path from UE_1, UE_2 and eNB, and the backward path is the reverse. It is supposed that there is a delay error when UEs does not successfully arrive at eNB. Therefore, for PS_{mn}, the delay loss $L_{mn}^{FP(Forward\ Path)}$ can be derived from the delay error, and the packet scheduling $PS_{mm}(x) = e^{-\delta_{mn}^{FP}(x)} (x \geq 0)$ can be derived from the delay loss between UEs and eNB, where δ_{mn}^{FP} is a delay constant. If eNB does not meet the delay loss between the forward path and backward path, the data packets sent by UEs will be correctly received by eNB at time T. Otherwise, eNB will encounter delay loss and packet overload. Therefore, the overload caused by the uplink path can be derived through the following equation:

$$PS_{mn}^{Uplink\ Path}(T - \overline{T}) = (1 - L_{mn}^{Uplink\ Path}) \int_0^T PS_{mn}(x)dx \tag{3}$$

where $\overline{T}$ is the duration from UE to eNB.

Similarly, the Delay Loss (DL) from the downlink path can be derived through the following equation:

$$DL_{mn}^{Downlink\ Path}(x) = \delta_{mn}^{Downlink\ Path} e^{-\delta_{mn}(x)}, x \geq 0 \tag{4}$$

Therefore, the overload caused by DL can be derived as follows:

$$PS_{mn}^{Downlink\ Path}(\overline{T} - T) = (1 - L_{mn}^{Uplink\ Path}) \\ (1 - L_{mn}^{Downlink\ Path}) \int_0^T DL_{mn}^{Downlink\ Path}(x)dx \tag{5}$$

3.4 Overload Control Based on OCB

If the processing rates of the eNB and the requested packets from UEs are balanced, then the packet scheduling process is optimized. However, if the balance is violated, there will be overload. This section describes the overload control algorithm based on OCB.

Generally, the size for the packets in the D2D link is dynamic. However, we consider all fixed-sized packets and variable-sized packets to control the packet overload monitored by the uplink path and downlink path for the D2D link. Fixed-sized packets and variable-sized packets suffer from the same packet overload while allocating the resources in the uplink and downlink process.

To control the overload with OCB, we suppose the encoding rate and channel bandwidth between UEi and eNB.

Hence, the overload control metric $OL_{control}$ for the requested packets from UEs can be defined using the following equation:

$$OL_{control} = packet_i \times s_i \times \lambda - \frac{E_r}{BW} \tag{6}$$

Where λ $(0 \leq \lambda < 1)$ is a delay constant for any packet i, s_i is the length of the i^{th} packet, and E_r is the average encoding rate for the i^{th} packet.

After $OL_{control}$, the throughput for UEs can be optimized, and this throughput can be defined using the following equation:

$$U_{throughput} = \frac{\|CB(i)E_r(i)\|^2 \times \mu}{CI(i) + OL_{control}} \tag{7}$$

Where CB(i) is the channel bandwidth metric from UEs and eNB and μ $(0 \leq \mu < 1)$ is the bit error rate caused by other cells for the link i.

Under predefined OCB, the optimum scheduling measure can be founded by trying all possibilities. To guarantee the optimal performance for each UE_i, the packet scheduling requires channel information between UE_i and eNB. Therefore, if the overload control metric is applied to D2D link environments, it will be reduced the D2D link management cost and overhead.

4. Simulation Results

We simulated the proposed mechanism to evaluate the system performance. We considered the three Generic Packetized Protocol (3GPP) macro-cell propagation environment presented in[13]. The simulation has applied a single cell, and the simulation parameters are as follows: link spectrum 16dB, uplink bandwidth 5MHz, and the maximum bit rate is 2.55 Mbps; the packet length is 512 kbps; the maximum data link bandwidth is 10/100 Mbps; and the average link bandwidth is 1.44 Mbps. Table 1 shows the simulation parameters.

Table 1. Simulation parameters

Parameters	Values
Channel bandwidth	255MHz
Carrier frequency	2.5GHz
D2D link spectrum	16dB
Uplink bandwidth	7.5MHz
Downlink bandwidth	2.5MHz
Maximum bit rate	5.25 Mbps
Average packet length	512 kbps
Maximum data link bandwidth	10/100 Mbps
Packet delay constant	5e-7s
UEs population per cell	5
Cell radius	200m
Target link spectrum	5.2dB
λ	$(0 \leq \lambda < 1)$
μ	$(0 \leq \mu < 1)$
Time stamp	t_s[1, 20s]

We assume an open power loop power with delay loss and assumptions on the network includes full buffer traffic for the packet scheduling. Negative-acknowledgement (ACK/NACK) packets signal the success of the overload control, assuming a bit error rate of 5%. In addition, the HARQ has incremental redundancy with a maximum of three retransmissions. To see the performance of the proposed mechanism, we applied the parameters under Table 1. We compare the D2D-Random and TRM scheme[3], and Figure 2 and Figure 3 show the throughput with λ and μ.

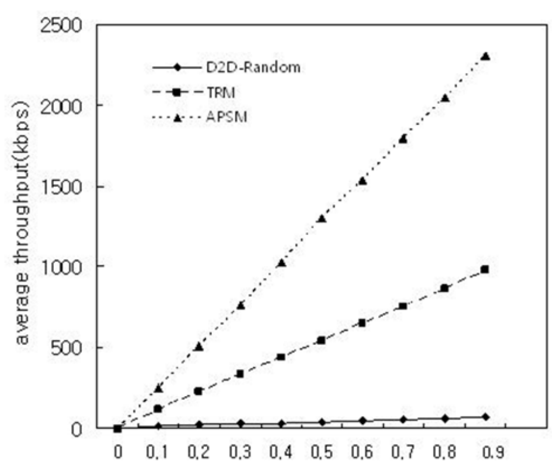

Figure 2. Average throughput with λ.

Comparing "D2D-Random" and "APSM" setups, we can see that the use of the proposed mechanism in the D2D link environment does not affect the overload caused by delay loss. Instead, enabling of overload detection has improved the average throughput. In this paper, the proposed mechanism does not take into account the possible packet scheduling to the other items of UE into inter-cell. Table 2 shows the performance of the average cell throughput of each test when the bit error rate is 5%. We measured the average cell throughput by applying all the simulation parameters. The results showed that the proposed mechanism provide efficient throughput compared to that of the regular cellular network.

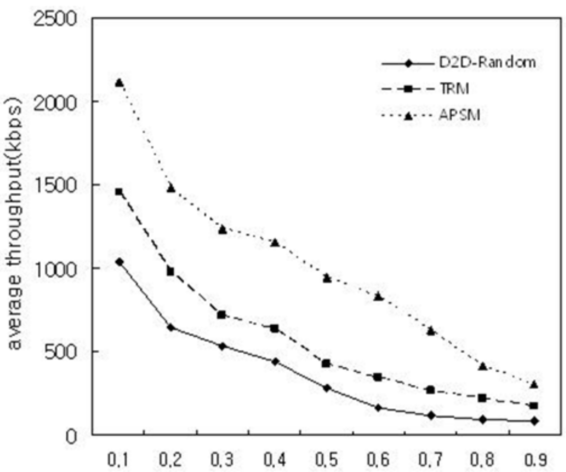

Figure 3. Average throughput with μ.

5. Conclusion

The resource interference and packet overload in the D2D link model degrades the Quality of Service (QoS) in resource shared networks and affects Device-to-Device (D2D) communications. A D2D communication underlaying LTE cellular network can more fully and efficiently use spectrum resources, and improve system throughput. This paper proposed an Adaptive Packet Scheduling Mechanism (APSM) for D2D communications over LTE-A networks. In the D2D link model, we considered the OCB to minimize the overload caused by the spectrum explosion and link congestion. The proposed mechanism has applied the HARQ, link adaptation process enabling the overload detection procedure to improve the average throughput. Simulation results showed that the proposed mechanism provides more efficient throughput compared to that of the regular cellular network.

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