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ADAPTIVE D2D COMMUNICATION WITH INTEGRATED IN-BAND AND OUT-BAND SPECTRUM BY EMPLOYING CHANNEL QUALITY INDICATOR

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Abstract

Device to Device (D2D) communication is considered valuable technology for 5G and beyond mobile networks. Current D2D approaches consider either in-band D2D communication mode at licensed spectrum or out-band D2D communication mode at unlicensed spectrum. Interestingly, available D2D modes show different advantages and disadvantages in terms of interference issues and spectral efficiency. Therefore, there is no clear winner to implement one perfect mode D2D communication solution. This paper proposes adaptive D2D communication approach with integrated in-band and out-band spectrum in order to improve overall network performance. The proposed approach takes into account normal cellular communication and both D2D communication modes benefiting from available resources in both the licensed and unlicensed bands. Also, it provides simultaneous utilization of licensed and unlicensed spectrum during higher bandwidth requirements and different mobile applications working at the same time. The proposed approach also implies the Channel Quality Indictor CQI to switch between proposed communications modes. Simulation implementation and evaluation reveal the significant performance gain especially in network delay and system capacity.

Keywords: 5G, D2D, In-band, Out-band, Proximity server.

1. Introduction

Today's cellular networks are burdened with rapid growth of mobile data traffic that comes from dozens of mobile applications. The users with several mobile daily routine applications with high demanding bandwidth has become harder to satisfy. New paradigms are opened to overcome the significant challenges of cellular networks, especially for 5G mobile networks. Many emerging technologies are introduced such as Millimeter Wave (mmWave) transmission, Massive Multiple Input Multiple Output (MIMO), Cognitive Radio (CR), Software Defined Networking (SDN), Device to Device (D2D) Communications, and so on [1, 2].

In current mobile networks, the base station is considered the main part that allow mobile devices connected with each other through mobile network. Existing base stations suffer from larger number of mobile devices, especially at big cities with high population density. Mobile operators try to add additional base stations to cope with such circumstances. However, the operators confront several challenges of infrastructure costs and the level of the power usage to support satisfactory end user services. Various studies were introduced to enhance the connection paradigm of the current cellular networks. The D2D communication is one of the novel paradigms for 5G mobile network that may offer enhanced connection and transmission approach.

The D2D communication is a promising technique that may reduce the pressure on the infrastructure of the current cellular networks. In normal mobile communications link, the traffic must go through core network even when the two mobile devices are close to each other. In contrast, in D2D communication; the mobile devices in short range can communicate with each other directly without traversing the base station or core network [3]. The D2D communication technique provides several benefits, such as improving spectral efficiency, raising throughput, reducing delay, and improving the energy efficiency [4].

Depending on the spectrum in which D2D communication occurs, the D2D communication can be classified into two categories: In-band and Out-band, as shown in Fig. 1 [5]. In case of the in-band communication, the cellular and D2D communication links use the licensed spectrum (cellular spectrum) of the mobile network. The motivation for using in-band D2D communication is high control capability over licensed spectrum. However, there is an interference challenge at the licensed spectrum during in-band D2D communication mode. In-band D2D communication is further divided into two parts: *underlay* and *overlay*. In *underlay* D2D communication mode, the cellular and D2D communication shares the same radio resources; meanwhile, dedicated radio resources are given to D2D communication links in *overlay* D2D communication mode [5, 6].

In order to overcome the interference issue between cellular and D2D communication in the in-band category, the out-band D2D communication can be used. Out-band D2D communication may exploits the unlicensed spectrum provided by the extra interface in mobile device, as explained in Fig. 2 [6, 7]. Unlicensed spectrum refers to other wireless technologies, such as Wi-Fi and Bluetooth. Out-band D2D communication can be divided into two parts: *controlled* and *autonomous*. The interface of the unlicensed spectrum is controlled by the operator of the mobile network in the *controlled* out-band D2D communication; meanwhile, the mobile network manages all communication links but leaves the

D2D communication to the other interface technology in the *autonomous* out-band D2D communication [2, 8].

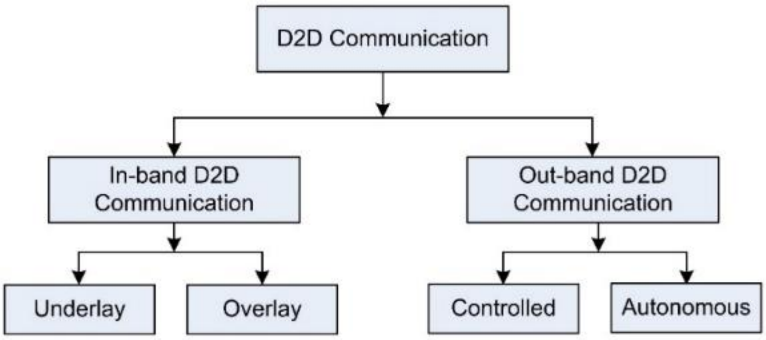

Fig. 1. Classification of D2D communication [5].

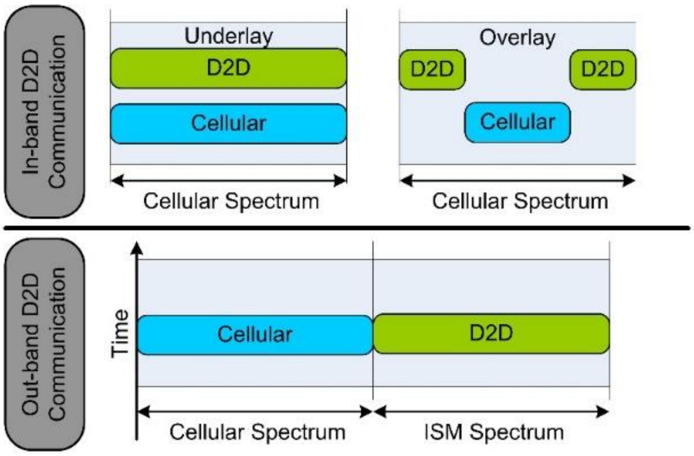

Fig. 2. Schematic representation of in-band and out-band D2D communication [6, 7].

There is a growing interest from academia, industry, and standardization bodies for D2D communication as a valuable property in 5G and beyond mobile networks. Even though there are growing attention in both in-band and out-band D2D communication categories, each of these categories may show different advantages and disadvantages in terms of interference issues, spectral efficiency, and system complexity. Hence, there is no superior mode, and the efforts of each category may depend on the use case scenario.

The current researches on D2D communication choose one of the aforementioned categories; either in-band mode at licensed spectrum or out-band mode at unlicensed spectrum, in their studies. Then, suggest algorithm to deal with some challenges to overcome the resulting complications; such as interference management, energy efficiency, and resource allocation. Nevertheless, focusing on single mode D2D communication by using one of the D2D communication modes only may limit the overall performance to interference profile of the used network. However, there is no concrete agreement on which D2D mode is better since each one of these D2D communication modes shows several challenges under given network environment. Moreover, the literature lacks the consideration of utilizing both in-band and out-band D2D communication modes simultaneously. Therefore, this paper aims to overcome the gap of single mode D2D communication by employing multimode D2D communication with simultaneously utilization consideration.

The main contribution of this paper is to design an adaptive D2D communication approach with in-band and out-band spectrum integration in order to obtain improved network performance. The proposed approach may consider all possible communication types for normal cellular and D2D communication modes benefiting from available resources in both the licensed and unlicensed bands. The proposed method is then evaluated and analysed using network simulation tool.

The rest of this paper is organized as follows: Section 2 presents the related works on D2D communication technology. The system model design and operation are illustrated in Section 3. Section 4 describes the system implementation and the simulation outcomes. Finally, Section 5 concludes the paper.

2. Related Work

The D2D communication has received a crucial attention as a new enabling technology for 5G mobile networks and beyond. The majority of the existing works focused on the in-band D2D communication using licensed spectrum motivated by high control of cellular spectrum. However, there is a considerable number of works proposed out-band D2D communication solutions to exploit the unlicensed spectrum of other wireless technologies. A detailed survey of the main characteristics of D2D communication along with useful overview of the categories, architecture, and features can be find and explained in [3, 9-11].

Even though there are various research studies addressing different challenges and issues on the D2D communication technology, these studies are limited to either in-band D2D communication or out-band D2D communication modes. Notably, each one of these D2D communication modes has its own pros and cons, and then poses several challenges under given environment. However, there are very few works try to study the benefits from both D2D communication modes. Below, we present and analyse the works that provide an attempt to use both in-band and out-band D2D communication modes in their proposals.

Asadi and Mancuso [12] introduced a D2D communication protocol considering coexistence the LTE and WiFi networks. The authors proposed WiFi clusters. The cluster head is responsible to communicative with LTE network. However, this may limit the traffic between base station the cluster devices to the bandwidth of the cluster head. Condoluci et al. [7] tried to provide a performance comparison for two available D2D communication technologies, i.e., between LTE direct and WiFi direct considering wide set of scenarios.

Kang et al. [13] proposed a traffic steering scheme considering three types of transmission links: cellular links, D2D links on licensed band, and D2D links on unlicensed band. The authors claimed for increase system capacity and improving Quality of Service (QoS) for users. This work shows several challenges: First, the study focused on the offloading scenario when the two mobile nodes (MNs) make a session in the same cell which can be serviced by licensed or unlicensed spectrum.

Second: this study is limited to analytical evaluation and authors assume single cell environment for D2D communication. Third, the authors assumed that the MNs have the capability for normal cellular links or D2D communication links, but unable to exploit them simultaneously.

Girmay et al. [14] suggested that the D2D users may reuse the licensed spectrum or share the unlicensed spectrum with incumbent WiFi users. However, the authors focused on managing the interference at 5 GHz unlicensed frequency between cellular and WiFi users when the LTE cellular network are allowed to operate in the same WiFi band. Also, the study only examined system throughput through numerical simulation. A similar work presented by Feng et al. [15] which provided a D2D communication in licensed spectrum to assisted traffic offloading from cellular network to WiFi network. Even though the authors considered an integrated cellular-WiFi network, the proposed D2D communication happened only at licensed band. The D2D communication at the licensed band is used to direct the traffic of the cellular users to WiFi network via unlicensed band. This scheme was evaluated analytically which is another weakness of the study.

Chung [16] presented an efficient transmission algorithm with effective power assessment and bandwidth allocation in D2D-assisted cellular networks. The authors try to use the available bandwidth of the two types of D2D communication bands, and then assign a dedicated mode for each D2D communication pair based of the required transmission rate. Thus, there is one D2D communication mode for each pair in the coverage area of base station. However, the author focused on bandwidth allocation and ignored other important issues such as interference management. In addition, the authors didn't mention which type of in-band (underlay or overlay) and which type of out-band (autonomous or controlled) used in their proposed work. Moreover, the author failed to insure the required bandwidth for all users. The analytical model considers many assumptions with only one base station consideration that causes several limitations in terms of system evaluation and performance.

Asadi et al. [17] proposed a floating band D2D communication considering multi-band D2D communication with underlay in-band, overlay in-band, and out-band D2D communication modes. Even though the authors try to benefit from underlay and overlay of in-band D2D communication, it is hard to use them synchronously at the same network cell. Also, using overlay in-band D2D communication with dedicated frequency resources may reduce the number of achievable resources for normal cellular communication. Moreover, the authors didn't mention if the out-band D2D communication was controlled by network or by the users (autonomous or controlled out-band D2D communication). The numerical simulation is the major drawback of this study. Furthermore, the authors tried to deal with interference issues during in-band D2D communication and ignored such possibility during out-band D2D communication.

Lin et al. [18] developed a hybrid architecture for D2D communication in which the Bluetooth and WiFi used as an out-band D2D communication mode and cellular spectrum for in-band D2D communication mode. This study divided the cellular cell into two clusters, where each cluster has its own cluster head. Inside the cluster, the devices can transfer traffic directly to each other using out-band D2D communication through WiFi, meanwhile the cluster head maintains the traffic between clusters using in-band D2D communication. This study involves system bandwidth challenge where the unlicensed spectrum is limited inside the cluster and the licensed spectrum is only used between cluster heads. Furthermore, broadcasting periodic message by cluster head is considered the main drawback of this work since this may consumes the device battery power. Moreover, incorporating Bluetooth in D2D communication technology may add additional complexity to the system. This work evaluated analytically.

Overall, the previously mentioned works highlighted few attempts for using in-band and out-band D2D communication modes together. However, these works have several limitations and challenges in their proposals, complexity, and performance. Moreover, these studies limited to analytical evaluation with several assumptions, considers single cell environment, ignore the interference issue at the out-band D2D communication, ignore the possibility of using both in-band and out-band communication simultaneously, and ignore the work of the proximity server in D2D communication architecture.

The aim of this paper is to propose an adaptive D2D communication approach with integrated in-band and out-band spectrum in order to improve the overall network performance. The proposed approach takes into account normal cellular communication and two D2D communication modes benefiting from available resources in both the licensed and unlicensed bands. Thus, the study benefits from the heterogeneity of future mobile networks. A simulation implementation of the proposed approach is then provided to evaluate its performance on mobile network.

3. Proposed System Design

The global standardization committees that suit D2D communication technology are either family of 3GPP standards or family of IEEE standards. The former is responsible for LTE-A standard which characterize in-band D2D communication while the latter is responsible for WiFi standard which characterize out-band D2D communication. These committees provide up to date features for their standards.

Generally speaking, in-band D2D communication underlay cellular spectrum may provide QoS management since the cellular and D2D communications can be controlled by the base station. However, the interference management and the power control are considered high complexity algorithms at this band. Also, there is no possibility of simultaneous use of Cellular and D2D communications. Notably, the underlay mode appears more popular than overlay mode in the in-band D2D communication due to wasted cellular resources that may be occurred during overlay mode. Different from in-band D2D communication, there is no need for cellular resources at the out-band D2D communication as it exploits the unlicensed spectrum. Hence, cellular resources allocation become easier as there is no interference management. Nevertheless, the interference in unlicensed spectrum takes into consideration during out-band D2D communication. In addition, cellular communication and out-band D2D communication can be operated simultaneously since they are using different spectrum bands. Particularly, the controlled mode is more valued than autonomous mode in the out-band D2D communication [19]. This is because the network assisted solutions provides suitable time and energy efficiency during peer discovery between two mobile devices. Thus, the base station can provide a considerable control over cellular devices to reduce the scanning beacons between mobile devices [20].

It is worth noting that the architecture of D2D communication consists of a proximity server in order to manage D2D communication operation. The proximity server provides a connection between proximity services of D2D communication and mobile network. The proximity server discovers the proximity between two cellular devices to trigger direct D2D communication mode when they are close to each other. Consequently, the operation of proximity server can be divided into two parts: D2D discovery and D2D communication. The discovery part is considered the main challenge for proximity server since the two mobile devices should identify each other before starting direct D2D communication. The proximity server then enables the direct D2D communication part once it determines the proximity of two mobile devices.

Accordingly, the available D2D communication modes show various pros and cons, and there is not a dedicated D2D communication mode that may provide a perfect solution. Therefore, we design an adaptive D2D communication scheme by integrating both the in-band and out-band D2D communication in one communication solution. The proposed solution support normal cellular communication and D2D communication with the capability of exploit them simultaneously. The adaptive solution proposed five types of communication modes as shown in Fig. 3. These proposed communication modes are summarized in Table 1.

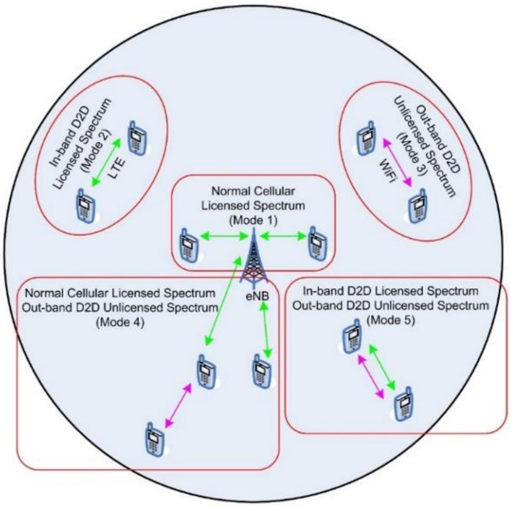

Fig. 3. System model architecture

Table 1. Proposed communication modes.

Mode	Descriptions	Spectrum
Mode 1	Normal cellular communication	Licensed cellular spectrum
Mode 2	Underlay in-band D2D communication	Licensed cellular spectrum
Mode 3	Controlled out-band D2D communication	Unlicensed WiFi spectrum
Mode 4	Simultaneous Cellular and controlled out-band D2D communications	Integrated Licensed and unlicensed Spectrum
Mode 5	Simultaneous Underlay in-band D2D and controlled out-band D2D communications	Integrated Licensed and unlicensed Spectrum

The proposed system works as follows: when a new communication session at the network is requested, the base station needs to decide which communication mode to select; either normal communication mode or D2D communication mode. If D2D communication is selected, the base station may decide either in-band or out-band D2D communication modes. Furthermore, in case of higher bandwidth requirements of different applications, the proximity server at the base station may simultaneously use two modes. The proximity server benefits from the information at the base stations to collect the necessary information for D2D communication mode such as the location of the mobile devices, Received Signal Strength Indicator (RSSI), application type, flow type, and so on. Figure 4 depicts the flowchart of the proposed system.

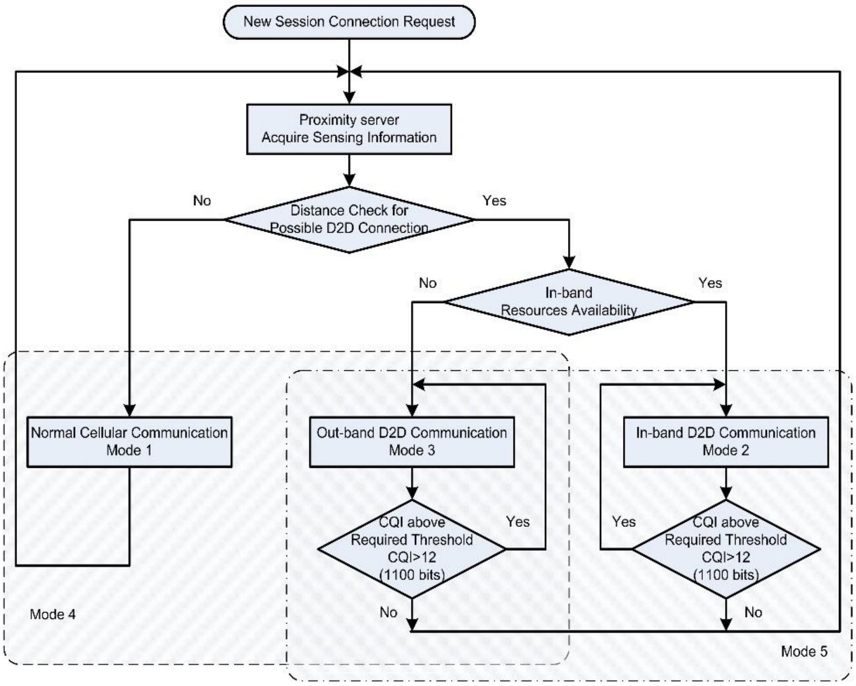

Fig. 4. Flowchart of the proposed system operation.

To determine the communication mode, the proximity server first checks the location of the mobile devices if they were at same cell or neighbouring cells. This is to identify the possibility of using D2D communication mode. However, there is a possibility of D2D communication when two mobile devices are in proximity to each other, but they are in neighbouring cells. When the two devices are not close to each other, then; the base station set mode 1 of normal cellular mode. In case the proximity server at the base station detects the possible proximity of two mobile devices, it notifies them to exchange beacons signals to measure RSSI between them. These devices then inform the proximity server. This is to avoid the most challenge issue in previous works which depends on the signal between mobile device and base station [13, 15, 17]. Once the proximity server detects that RSSI is suitable for direct D2D communication, it selects either in-band or out-band D2D communications depending on the priority, bandwidth, available resources, and other setting. The underlay in-band D2D communication in proposed mode 2 is most preferred when there are available resources in the cellular licensed spectrum.

Otherwise, mode 3 of controlled out-band D2D communication is applied using WiFi direct at unlicensed spectrum.

To provide a significant QoS, the proximity server periodically checks Channel State Information (CSI) between each D2D pair based on RSSI and Signal to Interference Noise Ratio (SINR) to identify the channel quality and interference in the operating spectrum, Channel Quality Indicator (CQI). In case of limited resources or strong interference during mode 2 of underlay in-band D2D communication at the licensed spectrum, the proximity server forced D2D pair to use mode 3 of controlled out-band D2D communication at the unlicensed spectrum. Similarly, the proximity server request D2D pair in mode 3 to use another WiFi channel when there is high interference issue at the unlicensed spectrum, otherwise; forced to use mode 2 of underlay in-band D2D communication at the licensed spectrum. Equally important, the proximity server monitors D2D condition to judge if the mobile devices continue using D2D communication or switch to normal cellular mode. As the two mobile devices pair moving out of mutual signal coverage of each other, the RSSI signal decreased until reached to a predefined value. At this moment, the proximity server request base station to prepare for normal cellular communication for those two devices.

The proposed system can also provide simultaneous utilization of licensed and unlicensed spectrum during higher bandwidth requirements and different mobile application services working at the same time. First scenario considers mode 4 with integrated licensed and unlicensed spectrum which can be applied when one application works through normal cellular communication at licensed spectrum, while there is another application can be used the controlled out-band D2D communications at unlicensed spectrum to transfer the data between two D2D communication in multi-hop condition. A similar scenario, mode 5 also allowed licensed and unlicensed spectrum integration in which there are two applications between pair of devices with higher bandwidth requirements to transfer the traffic over two possible D2D communication bands (underlay in-band and controlled out-band). These two scenarios of integrated multi-band spectrum are performed when the resources in one mode is not sufficient to perform QoS communication of these requested applications. Program 1 presents a Pseudocode of the proposed algorithm.

Program 1. Pseudocode of the proposed algorithm

Pseudocode of Proposed Communication Algorithm

```
Start
SWITCH (CBR)
CASE 1 (CBR=1)                                    // One Application Running//
  Proximity Server
  READ RSSI
      IF RSSI < D2D Threshold THEN
            Set Mode1 Communication
      ELSE IF Inband Resources > D2D Required Threshold THEN
            Set Mode2 Communication
            READ Inband CQI Channel
                  IF Inband CQI > 12 THEN
                        DO NULL
                  ELSE
                        Goto Proximity Server
                  END IF
      ELSE
            Set Mode3 Communication
            READ Outband CQI Channel
```

```
                        IF Outband CQI > 12 THEN
                                DO NULL
                        ELSE
                                Goto Proximity Server
                        END IF
                END IF
        CASE 2 (CBR=2)                              // Two Applications Running//
            READ Inband CQI Channel
                IF Inband CQI < 12 THEN
                        Set Mode4 Communication
                ELSE
                        Set Mode5 Communication
                END IF
        End
```

4. Simulation Implementation and Results

The proposed system model has been developed and implemented using network simulator NS2 with the consideration of heterogeneous wireless networks [21, 22]. The developed model utilizes the five possible types of communication modes of the proposed system. The evaluation process examines performance of the dedicated cellular and a dedicated in-band or dedicated out-band D2D communications compared with the proposed system of the adaptive D2D communication with integrated in-band and out-band spectrum. The network topology of the system is illustrated in Fig. 5. The network consists of seven cellular cells connected to Gateway. The default link delay between Gateway and each cell is considered 1 millisecond, where the default simulation parameters are summarized in Table 2. Moreover, to provide WiFi communication, there is one WiFi access point at least at each cell. The Gateway is supported with proximity server to maintain D2D communication. The proximity server may collect all the necessary information regarding D2D communication, such as Mobile Node (MN) location, RSSI, application type, and so on for each MN. Thus, Gateway is responsible of the overall connectivity and traffic flows in the network. The MN in the developed system is supported with two wireless interfaces communication technology, one for cellular communication in licensed spectrum and the other for WiFi communication at unlicensed spectrum.

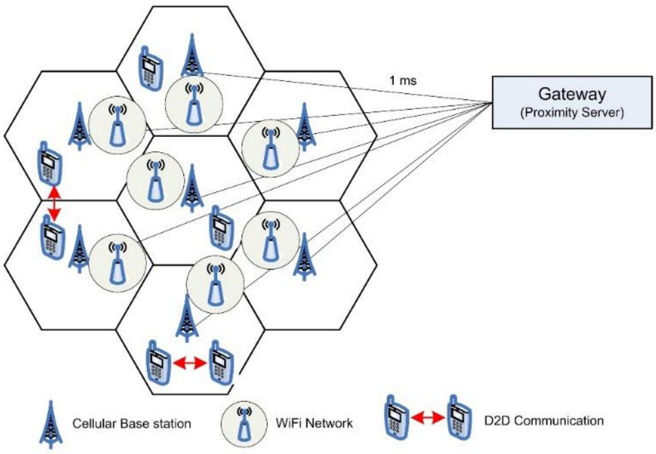

Fig. 5. Network topology of the simulation model.

Table 2. Default Simulation parameters.

Parameter	Default Value
Simulation Area	3000 meters×2000 meters
Wireless Network Environment	Heterogeneous (Cellular+WiFi)
Propagation Model	Two Ray Model
Routing Protocol	DSDV
Mobile Device Speed	5 m/s
CBR Packet Size	1000 Bytes
CBR Packet Interval	0.01 second
Access Network to Gateway Delay	1 ms
Access Network to Gateway Bandwidth	100 Mbps
Radius of Cellular Coverage Area	200 m
Radius of WiFi Coverage Area	100 m

At the starting of simulation, the proximity server registers all mobile nodes in its database and continuously check their locations for possible D2D communication links. Each mobile node is connected with its pair (Mode 1) through Gateway or base station of the mobile network. During mobile nodes movements, the proximity server checks the possibility of direct D2D communication based on the locations of these nodes. Consequently, the proximity server asks to exchange beacons signals between these devices to identify the required RSSI between them. After that, the proximity server checks the CQI of the cellular network cell if it is suitable for in-band D2D communication (Mode 2), otherwise; forced to use out-band D2D communication (Mode 3). The proximity server also continuously monitors the CQI of the used network to switch between these communications modes for best performance quality.

Figure 6 presents the end-to-end delay at the network assuming one mobile application (i.e. one Constant Bit Rate CBR generator) at different communication modes. At normal cellular communication, the average end to end delay gives about 10 ms, and at underlay in-band D2D communication shows about 7.6 ms, meanwhile the controlled out-band D2D communication gives 1.6 ms average end to end delay. It can be noted that the packets during in-band D2D communication provides about 2.4 ms lower end to end delay compared to normal cellular communication. This is related to the delay at the infrastructure network which caused by links delay between base stations and the Gateway during cellular communication, in addition to the processing and queuing delays at the network. However, the in-band D2D communication shows higher end to end delay compared to out-band D2D communication as the WiFi interface specified with higher data rates and bandwidth capabilities. Thus, the out-band D2D communication mode provides the best end to end delay metric at the network.

Figure 7 illustrates the average end to end delay during five possible communication modes of the proposed system considering two high speed mobile applications (i.e., two CBR generators). Similar to previous figure, the average end to end delay of the out-band D2D (mode 3) communication is lower than in-band D2D communication (mode 2), while the last one produces lower average end to end delay than normal cellular communication (mode 1). In mode 4 the proposed system may simultaneously use the cellular network for first application and uses the controlled out-band D2D communications for the second application. Therefore, mode 4 generates higher average end to end delay than modes 2 and 3 and lower than mode 1. This is due to passing the packets of one application through the licensed spectrum of network infrastructure while the other moves through unlicensed spectrum band. However, mode 5 simultaneously employs the underlay in-band D2D communication at licensed spectrum for one mobile application and utilizes the controlled out-band D2D communication at the unlicensed spectrum for the other application. Thus, mode 5 produces lower average end to end delay than mode 4 since the last one process one of the two applications at the network infrastructure which causes higher delay. Moreover, mode 5 produces higher average end to end delay than mode 3. This attribute is related to one application at mode 5 is applied at in-band licensed spectrum which may produces high end to end delay compared to mode 3 where the two mobile applications are moved through unlicensed out-band spectrum with lower average end to end delay.

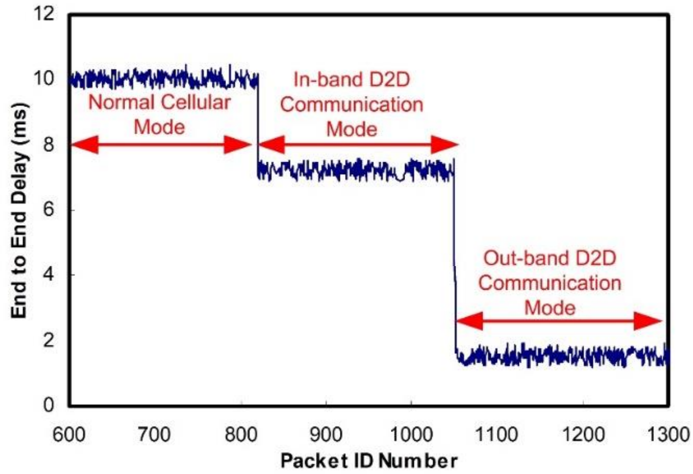

Fig. 6. End to end delay during normal cellular, in-band D2D, out-band D2D communications.

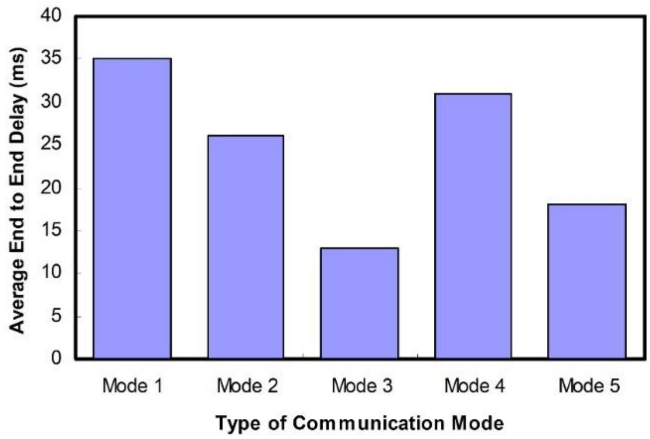

Fig. 7. Average end to end delay of the five communications modes considering two mobile applications.

Figure 8 shows the throughput performance obtained during different communication modes. It can be observed that the in-band D2D communication generates an average of 36 Mbps throughput performance which is higher than normal cellular communication with 22 Mbps throughput. The reason is related to higher bandwidth availability during direct D2D communication against the limitations of the lines and other network components at the infrastructure during normal cellular communication. However, the throughput provided by out-band D2D communication; around 57 Mbps, is higher than in-band D2D communication since the WiFi link support higher bandwidth compared to cellular link.

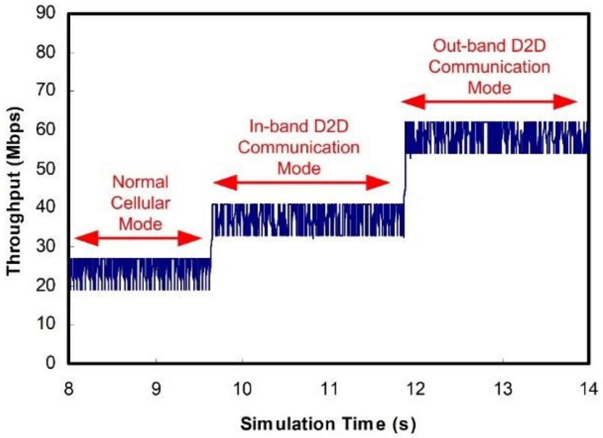

Fig. 8. Throughput of different communication modes.

The impact of the traffic load on the communication modes is shown in the Fig. 9. Generating various traffic patterns for presenting different data types can be obtained by varying the time interval between successive packets. In general, large packet interval represents low data rate application; such as voice, while low packet interval indicates high data rate application; such as video. Therefore, the small packet interval produces higher delay compared to large packet interval due to heavily traffic load, as shown in Fig. 9. However, the in-band and out-band D2D communication modes achieve lower average delay than normal cellular communication mode. This effect is related to the communication link delays between base stations and Gateway and the queuing and processing delays at these infrastructure components. Moreover, the out-band D2D communication mode obtained lower average delay than in-band D2D communication mode due to higher data rate and bandwidth capabilities.

Figure 10 depicts the number of D2D communication links on the average delay performance at the network. The simulation scenario is designed with 30 mobile nodes at the network, with 15 possible communication links between them; i.e., one link between each two nodes. After starting the simulation, all mobile nodes are connected with each other to make 15 communication links through the Gateway of the network infrastructure. Gradually, the simulation scenario produces one direct D2D communication links at time to examine the average delay at the network Gateway. The scenario considers 10 D2D communication links throughout the simulation; five of them are using in-band D2D communication mode while the other five utilize out-band D2D communication mode. In Fig. 10, the x-axes with the odd D2D connections interval considers in-band D2D communication link, while the even interval indicates out-band D2D communication link. This means that the simulation scenario considers one D2D communication connection after another to study the effect on the average network delay. It can be seen that the resulted delay reduced gradually as the number of D2D communication links increased. Accordingly, the D2D communication modes may reduce the traffic load at the network infrastructure and then improves the operation of the network. However, the proposed system with different communication modes gives lower average network delay compared to conventional D2D communication that support either in-band or out-band communication modes. Hence, the proposed system enhanced the overall operation of the network.

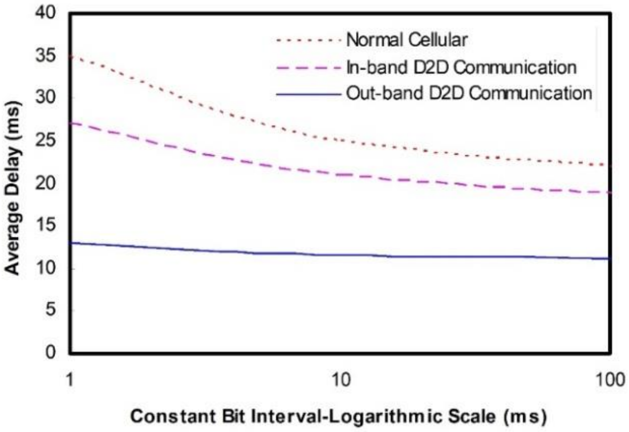

Fig. 9. Impact of the constant bit rate CBR on the average delay.

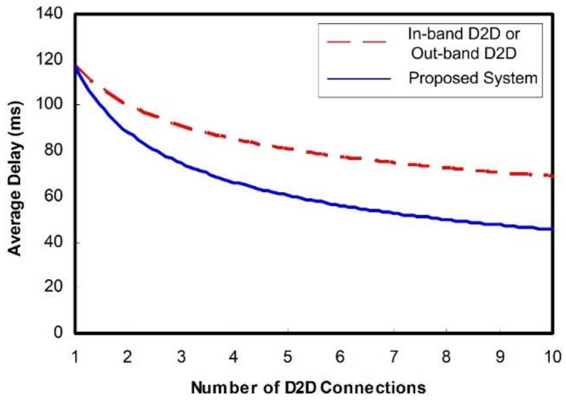

Fig. 10. Impact of the number of D2D connections on average network delay.

A similar simulation scenario of Fig. 10 is used to study the system throughput of the network in Fig. 11. The system throughput is referred to the aggregated throughput of the normal cellular and D2D communication modes. Clearly noted that the system throughput is increased with the increasing number of D2D communication pairs. It can be observed that the proposed system gives higher system throughput compared to the systems with only in-band D2D communication mode or out-band D2D communication mode. This attribute is related to the proposed system capabilities to make different cellular and D2D communication connections. Thus, the proposed system with various communication modes outperforms the current conventional systems with one D2D communication mode.

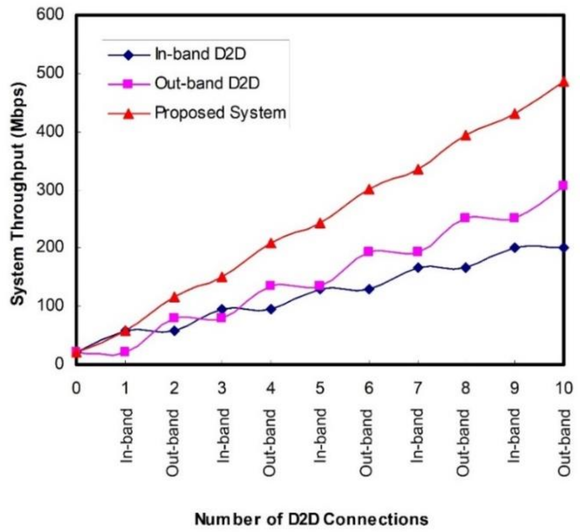

Fig. 11. Impact of the number of D2D connections on the system throughput.

To compare the obtained results with related works, it should be noted that these studies come up with mathematical evaluation where no detailed simulation are provided. Moreover, these studies implied single cell environment with many assumptions, and they didn't mention which type of in-band D2D and which type of out-band D2D communications were used, as can be seen in most relevant studies [13, 17]. In addition, they lack the interference issue consideration at both licensed and unlicensed bands. More important, they ignore the utilization of both in-band and out-band D2D communications simultaneously.

However, if we consider the re-implementation of relevant works [13, 17] using the same of our simulation scenario, our proposed approach may outperform these studies since they use *undelay* mode for in-band D2D communication and *controlled* mode for out-band D2D communication. Notably, the undelay mode overcome the wasted resources issues of the overlay mode in the in-band D2D communication, while the controlled mode provides suitable time and energy efficiency during peer discovery between two mobile devices compared to autonomous mode in the out-band D2D communication. Turning to the experimental simulation results presented in Fig. 10, it can be seen that the proposed approach provides 8% lower network delay at low number of D2D connections to around 42% lower network delay at higher number of D2D connections. Moreover, Fig. 11 shows an average of 47% increase in system throughput for the proposed approach compared to single mode D2D communication. Hence, the proposed approach outperforms current works [13, 17] during multimode operation and due to simultaneous utilization of both in-band and out-band D2D communications.

5. Conclusion

In this paper, we developed an adaptive D2D communication architecture approach which combines in-band licensed spectrum and out-band unlicensed spectrum to improve the overall network operation.

This approach proposed five communication types for normal cellular and D2D communication modes benefiting from available resources in both the licensed cellular and unlicensed WiFi bands. Also, it provides simultaneous utilization of licensed and unlicensed spectrum during higher bandwidth requirements and different mobile application services working at the same time.

The proposed approach examines the channel quality and interference to switch between different communications modes in order to insure flexible and efficient transmission mode selection.

The simulation implementation shows remarkable outcomes obtained for the proposed system at different network settings. The evaluated results verify the improvement of the network performance by reducing the network delay and significantly increasing the system capacity compared to the exiting methods. However, mode 3 with all out-band D2D communication outperforms other communication modes since it produces lower network delay and provides higher bandwidth. Thus, this proposed approach which exploits both in-band and out-band spectrum is considerably minimizing the pressure at the network architecture and enhance the overall network performance.

Future work may consider the security challenges of different types of D2D communication. Moreover, the application of D2D communication, such as in Vehicular network (VANET) requires further investigation.

References

1. Gupta, A.; and Jha, R.K. (2015). A survey of 5G network : Architecture and emerging. *IEEE Acess*, 3, 1206-1232.
2. Mumtaz, S.; Huq, K.M.S.; and Rodriguez, J. (2014). Direct mobile-to-mobile communication: Paradigm for 5G. *IEEE Wireless Communications*, 21(5), 14-23.
3. Gandotra, P.; Jha, R.K.; and Jain, S. (2017). A survey on device-to-device (D2D) communication: Architecture and security issues. *Journal of Network and Computer Applications*, 78, 9-29.
4. Thrimurthulu, V.; and Sarma, N.S.M. (2017). Device-to-device communications in long term evaluation-advanced network. *Proceedings of the* 2017 *International Conference on Intelligent Computing and Control Systems* (*ICICCS*), Madurai, India, 818-823.
5. Das, C.B. (2015). A study on device to device communication in wireless mobile network. *International Journal of Modern Communication Technologies & Research* (*IJMCTR*), 3(3), 1-5.
6. Asadi, A.; Wang, Q.; and Mancuso, V. (2014). A survey on device-to-device communication in cellular networks. *IEEE Communications Surveys and Tutorials*, 16(4), 1801-1819.
7. Condoluci, M.; Militano, L.; Orsino, A.; Alonso-Zarate, J.; and Araniti, G. (2015). LTE-direct vs. WiFi-direct for machine-type communications over

LTE-A systems. *Proceedings of the* 2015 *IEEE* 26*th Annual International Symposium on Personal, Indoor and Mobile Radio Communications* (*PIMRC*), 2298-2302.

8. Hashim, M.F.; and Abdul Razak, N.I. (2019). Ultra-dense networks: integration with device to device (D2D) communication. *Wireless Personal Communication*, 106(2), 911-925.
9. Kar, U.N.; and Sanyal, D.K. (2018). An overview of device-to-device communication in cellular networks. *ICT Express,* 4(4), 203-208.
10. Shah, S.T.; Hasan, S.F.; Seet, B.-C.; Chong, P.H.J.; and Chung, M.Y. (2018). Device-to-device communications: A contemporary survey. *Wireless Personal Communications*, 98, 1247-1284.
11. Liu, J.; Kato, N.; Ma, J.; and Kadowaki, N. (2015). Device-to-device communication in LTE-advanced networks: A survey. *IEEE Communications Surveys and Tutorials*, 17(4), 1923-1940.
12. Asadi, A.; and Mancuso, V. (2013). WiFi direct and LTE D2D in action. In the *Proceedings of IEEE* 2013 *IFIP Wireless Days* (*WD*), 1-8.
13. Kang, B.-J.; Choi, S.; Jung, S.; and Bahk, S. (2019). D2D communications underlaying cellular networks on licensed and unlicensed bands with QoS constraints. *Journal of Communications and Networks*, 21(4), 416-428.
14. Girmay, G.G.; Pham, Q.-V.; and Hwang, W.-J. (2019). Joint channel and power allocation for device-to-device communication on licensed and unlicensed band. *IEEE Access*, 7, 22196-22205.
15. Feng, B.; Zhang, C.; Liu, J.; and Fang, Y. (2019). D2D Communications-assisted traffic offloading in integrated cellular-WiFi networks. *IEEE Internet of Things Journal*, 6(5), 8670-8680.
16. Chung, Y.- L. (2017). Energy-efficient use of licensed and unlicensed bands in D2D-assisted cellular network systems. *Energies*, 10(11), 1893.
17. Asadi, A.; Mancuso, V.; and Jacko, P. (2015). Floating band D2D: Exploring and exploiting the potentials of adaptive D2D-enabled networks. Proceedings of the 2015 *IEEE* 16*th International Symposium on A World of Wireless, Mobile and Multimedia Networks* (*WoWMoM*), Boston, MA, USA.
18. Lin, Z.; Gao, Z.; Huang, L.; Chen, C.-Y.; and Chao, H.-C. (2015). Hybrid architecture performance analysis for device-to-device communication in 5G cellular network. *Mobile Networks and Applications*, 20, 713-724.
19. Fodor, G.; Dahlman, E.; Mildh, G.; Parkvall, S.; Reider, N.; Miklós, G.; and Turányi, Z. (2012). Design aspects of network assisted device-to-device communications. *IEEE Communications Magazine*, 50(3), 170-177.
20. Andreev, S.; Galinina, O.; Pyattaev, A.; Johnsson, K.; and Koucheryavy, Y. (2015). Analyzing assisted offloading of cellular user sessions onto D2D links in unlicensed bands. *IEEE Journal on Selected Areas in Communications*, 33(1), 67-80.
21. Issariyakul, T.; and Hossain, E. (2011). *Introduction to network simulator NS*2. (2nd Edition). Springer Science & Business Media, New York.
22. NS2 Network Simulator. Retrieved October 5, 2020, from from http://www.isi.edu/nsnam/ns.