A Novel Two Tier Architecture for Licensed Band Device to Device Communication in 5G Wireless Network.

Koushik Barman[1] and Ajay Roy[2]
School of Electronic and Electrical Engineering
Lovely Professional University, Punjab

Abstract

Conventional cellular network architecture allows full duplex communication between two user equipments using uplink and downlink channel through base station. But this architecture does not permit direct communication between devices and therefore inefficient to fulfil various advanced applications like vehicle to vehicle communication, context aware social networking and proximity based local emergency services, real time sensor data analysis, smart city and Internet of things (IOT) applications. To overcome this problem, this article presents two tier cellular architecture that involves a base station to device tier and device to device tier. This architecture allows direct communication among devices in device tier and traditional communication in cellular tier using licensed band spectrum. Furthermore, this paper is focused on detail investigation of various technological challenges to implement two tier architecture like resource allocation technique, interference management, pricing models and optimum service discovery protocols.

Keywords: *Device to device communication, 5G, Service discovery*

I. Introduction

Data traffic is increasing exponentially day by day. It has been projected that twenty billion devices will be connected to internet within the year 2025[1]. Traditional network is no more capable to handle huge data traffic demand. In every ten years mobile network is getting changed to adapt new technologies and moving from one generation to another. Cellular network is now at initial testing and implementation stage of fifth generation. Third generation partnership project group (3GPP) has already reported system architecture for the 5G System in release 15[2]. The 5G new radio allows low latency and ultra-reliability communication among devices using millimeter wave band. Various advance technologies like beam division multiplexing, massive MIMO antennas, network slicing etc. are integral part of 5G standard [1-3]. Although 5G has been reported by 3GPP but still it is not implemented in a large scale due to various constrain. D2D communication is first announced by 3GPP in release 12 as a part of LTE-A network where it is defined for proximity based services using cellular tier architecture [4]. Full-phase integration of device tier device to device communication is still an ongoing research topic and it will be considered as an essential feature of upcoming 5G standard. In bound D2D communication provides direct interaction among devices using licensed spectrum. Due to use of licensed cellular spectrum it provides high quality of service and centralize traffic monitoring facility. In traditional cellular network user equipments (UE) communicate through base station but in D2D, two UEs or multiple UEs communicate directly among themselves. In two tier network, data off-loading takes place among multiple device. A user under poor cellular coverage switched to device tier where it gets cellular support by another user equipment which is under cellular coverage. Device under cellular coverage may acts as a relay device and provide D2D communication to other devices which are out of cellular coverage. Therefore, two tier network not only allows data offloading of cellular tier but also it extend coverage of base station. As it allows data traffic to be routed via multiple devices directly, a higher level security challenges is the major constrain that need to be investigated in two tier architecture. Two tier networks permits ultra-reliable and low latency communication among devices in close proximity. A driver looking for parking area may need to check availability of parking slots near to him, someone spotting for specific group of people in a crowd may need to search the group of his interest, and firemen in duty may need to communicate among themselves during emergency. However optimal protocol for device discovery and service discovery is an ongoing research topic. More over availability of sufficient radio resources and allocation of those resources to devices for two tier network is another challenge. Lots of research is going on to develop resource allocation algorithm to achieve higher spectral efficiency and throughput [5, 6]. Inband D2D also allows to assign same time frequency block to the D2D user and cellular user using proper power control and interference management technique [7, 8]. Another aspects two tier device to device network is to design appropriate pricing model for network operator and end users so that they should motivated to participate in D2D communication. Incentives can be provided to the devices will act as a relay node to offload data traffic from base station to other devices which are out of coverage. In this article, we have presented a precise overview of these research challenges related to resource allocation, interference management, service discovery and pricing model for two tier network architecture. Also this article provides an insight on comparative analysis of various pricing models for device relaying nodes.

II. Overview of Two-tier D2D architecture

Fig.1 shows layout of possible architecture of two-tier device to device communication. The proposed architecture is focusing on four types of D2D communication scenarios e.g. (1) Operator control device act as a relay (OCDR), (2) Device control relay (DCR), (3) Device control direct communication (DCD) and (4) Operator control direct communication(OCDC). In Fig.1, user equipment (UEs) A, B, C along with the base station is representing OCDR model. In OCDR model, operator has full control on all devices which are participating in device to device communication. Here UE-A is working as a relay node. UE-A is offloading base station's traffic to UE-B and UE-C which are located at cell edge and having poor cellular coverage. Base station is unable to provide high speed data service directly to them because of distance constrain. Therefore, UE-A which is at full network coverage and have sufficient resources is sharing radio resources to UE-B and UE-C. UE-A may be awarded incentives by the operator for providing this service. In this scenario, UE-B and UE-C getting high speed data traffic from base station only if UE-A allows to utilize its bandwidth. On the other hand base station has full control on UE-A, UE-B and UE-C. Base station can decide resource allocation and pricing policies for UE-A, UE-B and UE-C, whereas UE-B and UE-C need to discover UE-A by an appropriate service discovery protocol to get data offloading service from UE-A. In DCR scenario, UE-D acting as relay and providing services to UE-E and UE-F. Communication between UE-E and UE-F is only possible if UE-D shares its resources. In this case base station has no role to play. Devices are controlled by a relay device which has supreme authority to establish D2D communication link. Resource allocation policies fully depends on devices rather than operator. Devices in this scenario should ensure interference not to have with other devices of same tier or macro tier while communicating with themselves. In case of DCD scenario shown in Fig.1, two devices UE-G and UE-H directly communicates between them in full duplex mode without base station. Resource allocation is controlled by devices rather than base station. In case of OCDC, UE-I and UE-J communicates with each other under the supervision of base station. Resource allocation and D2D link establishment policies are decided by base station only. Each of these two tire scenario having their own merits and demerits. Operator control scenarios e.g. OCDR and OCDC is preferable where security is more concern and centralize monitoring is prime priority. Device control scenarios are preeminent in case of proximity based file exchange services and local data off-loading services among devices where a dedicated frequency band can be allocated to the devices.

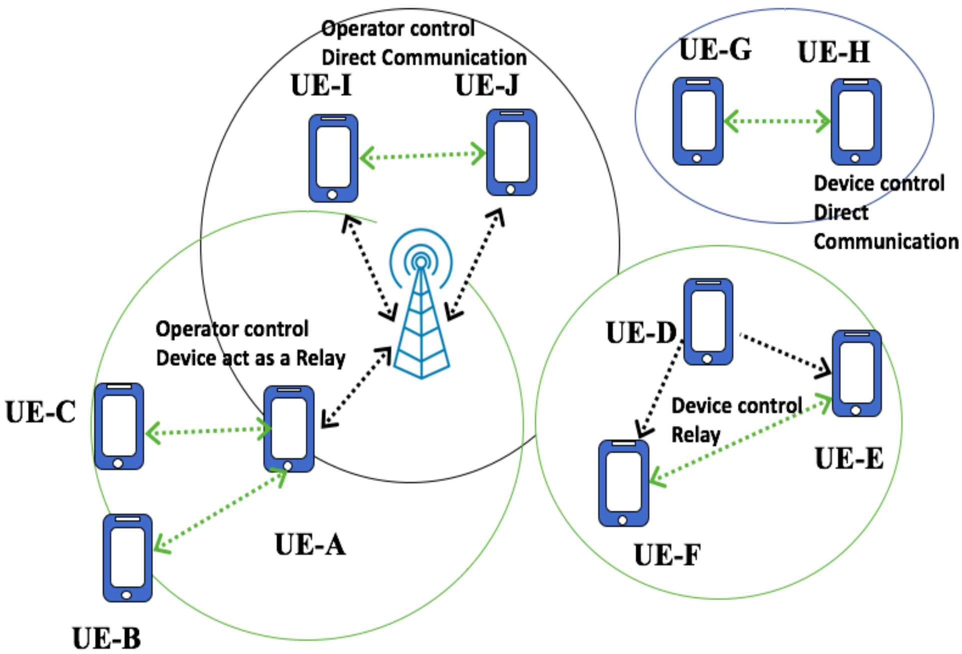

Fig.1 Two-Tier D2D communication architecture

III. Technical challenges of D2D two-tier network

In this section we have presented various technical challenges and recent research updates of D2D two tier network. First and foremost challenge is to design efficient service discovery protocols for device discovery and direct communication. Proximity service discovery is a process to discover UEs in close proximity for D2D communication. It includes both device discovery and service discovery.There are two types of service discovery protocols already exists for distributed network, named as reactive protocol and proactive protocol. A reactive protocol allows user equipment to discover and send service request to the neighbour UEs. In a device control scenario devices wish to discover another device for direct communication may use a reactive protocol for link establishment. Therefore, reactive protocol initials device tier communication link directly without intervention of base station. After receiving a service request, A UE may accept or reject the request by sending an acknowledgement to the UE who has initiated the request. In proactive service discovery protocol, base station periodically transmits location information of a group of nearby UEs who has registered for device discovery service and willing to do device to device communication. A UE can accept available request or may participate for device to device communication directly after sending an acknowledgement message to the base station. Base station holds all information related to location address and initiates D2D communication. Proactive protocol is suitable for operator control architecture such as OCDR or OCDC. As base station need to broadcast location information of devices periodically and all devices also need to be active all the time therefore it consumes more power than reactive protocol. Service discovery protocols in licenced band are reported in 3GPP release 12. According to 3GPP there are two protocols. Direct discovery protocols without help of base station and Evolved packet core (EPC) assist discovery protocols [3, 4]. These protocols work in LTE-A architecture as shown in Fig.2. According to this architecture, each user equipment has an inbuilt client application known as D2D proximity service discovery application. This application helps to establish a connection with D2D proximity application server using PC1 link. This server holds location information of all registered UEs under E-UTRAN. A proximity service function which is connected to D2D proximity application server via PC2 link is utilized by concern UEs to get information about D2D service registered UEs. Home Subscriber Server (HSS) authenticates the UE. Mobility Management Entity (MME) stores UE profile related proximity service information. SLP provides UE location information using SUPL.Table1 shows summery of available service discovery protocols. Feasibility study of these scenarios in 5G NR is still an uncovered area of research.

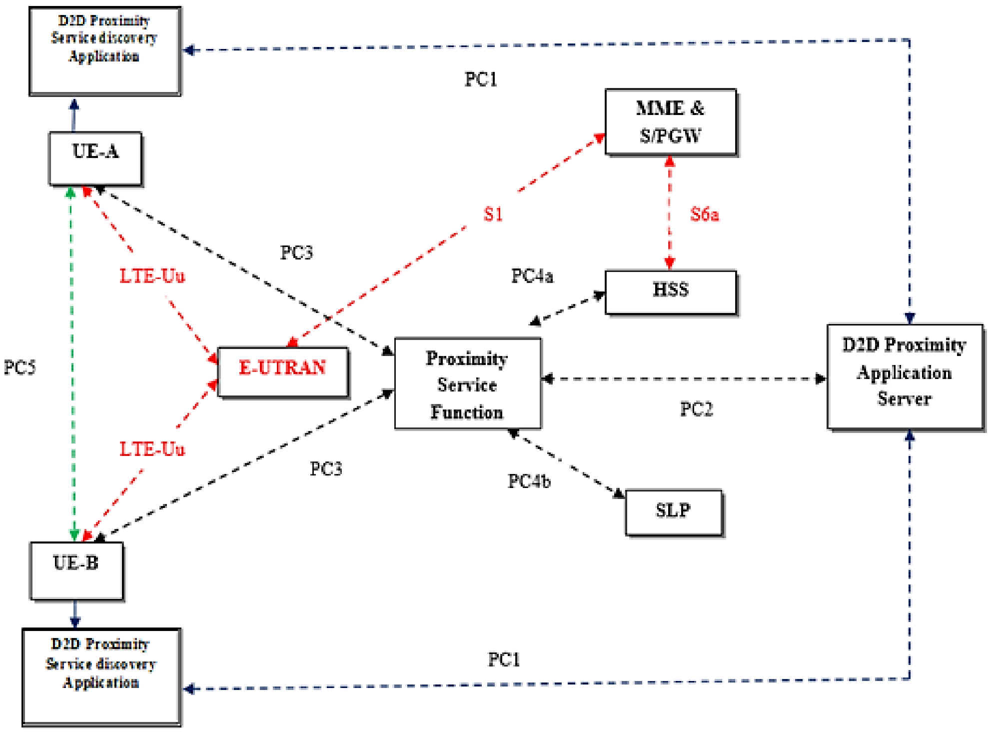

Fig.2. LTE-A architecture for supporting service discovery D2D communication.

The second important research challenge is to design appropriate resource distribution and interfering signal power supervision technique for D2D link establishment [9]. In a two tier network interference may degrade performance of the network in device tier as well as in cellular tier. Inbound device to device communication allows to reuse uplink or down link frequency band for assigning radio resources to the D2D users which creates interference problem to the existing cellular user. More the power level of D2D link makes the cellular link weaker. Hence, various power control techniques has been reported to overcome this problem.The objectives of interference management are minimization of Cellular Interference on nearby cellular link, Minimization of Cellular Interference on D2D link, minimization of D2D interference on cellular link and minimization of D2D interference on nearby D2D link. Fig.3 illustrates interference of D2D link on cellular link [10].

Table1. Existing service discovery protocol

Network Types	**Distributed Networks (MANETs/ WLAN/WiFi-Direct)**	**Centralized Networks(LTE-A)**
Device Discovery Mechanism	Proactive and Reactive	Direct discovery EPC assist discovery
Operating Frequency Band	Unlicensed ISM band	Licensed Band
Service Discovery protocol types	Carrier Sense Multiple Access	Direct discovery: Push mechanism based protocol EPC level discovery: Network assistance based protocol(Ref:ITU 3GPP release 12)
Limitations	1. Security Challenges 2. Resource allocation and management challenges 3. Protocol Overhead problems	Protocol design challenges in case of out of coverage area of eNodeB

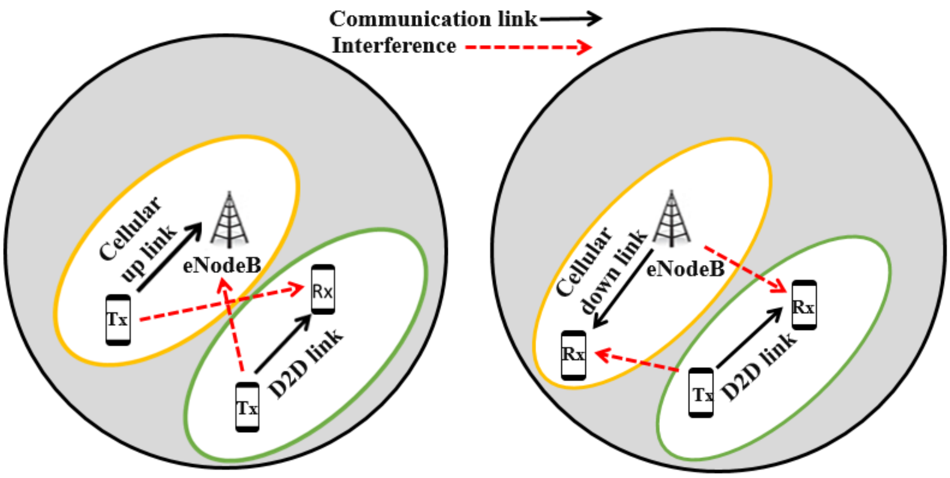

Fig.3. Interference of D2D link on cellular uplink and downlink.

To overcome interference challenges mode selection based approaches are preferable [11]. In this strategy, three different modes are defined by administrator during allocation of resources to the devices e.g. cellular mode, reuse mode and dedicated mode. This modes are selected by operator based on received channel state information (CSI). CSI depends on received signal to noise plus interference ratio, signal outage probability and channel throughput requirement at the destination UE.Let $P_{i,j}$ is the transmitted power of transmitter of i^{th} D2D pair on the j^{th} time frequency block, then signal power to interference power plus noise ration can be calculated as, $\gamma = \frac{P_{i,j}\ h_{i,i}}{P_{k,j}\ h_{ki} + No}$ and throughput of i^{th} D2D pair on the j^{th} resource block can be evaluated using Shannon's theorem of channel capacity, e.g. $C(P_{ij}) = W \log2 (1+\frac{P_{i,j}\ h_{i,i}}{P_{k,j}\ h_{ki} + No})$, where W=channel bandwidth, h_{ii} = channel gain, h_{ki}=channel coefficient of interference link. N_o = Gaussian noise power, $P_{k,j}$= transmitted power in cellular link.Fig.4 shows conceptual flow chart of mode selection based resource allocation technique. Another approach to control interference is to use precoding technique at the D2D transmitter [11]. Codebook based precoding can be utilize for this purpose. Base station need to be aware about the channel state information for the implementation of codebook based precoding. At the receiver, interference signal can be demodulated and used to cancel interference which will improve signal to interference pulse noise ratio.

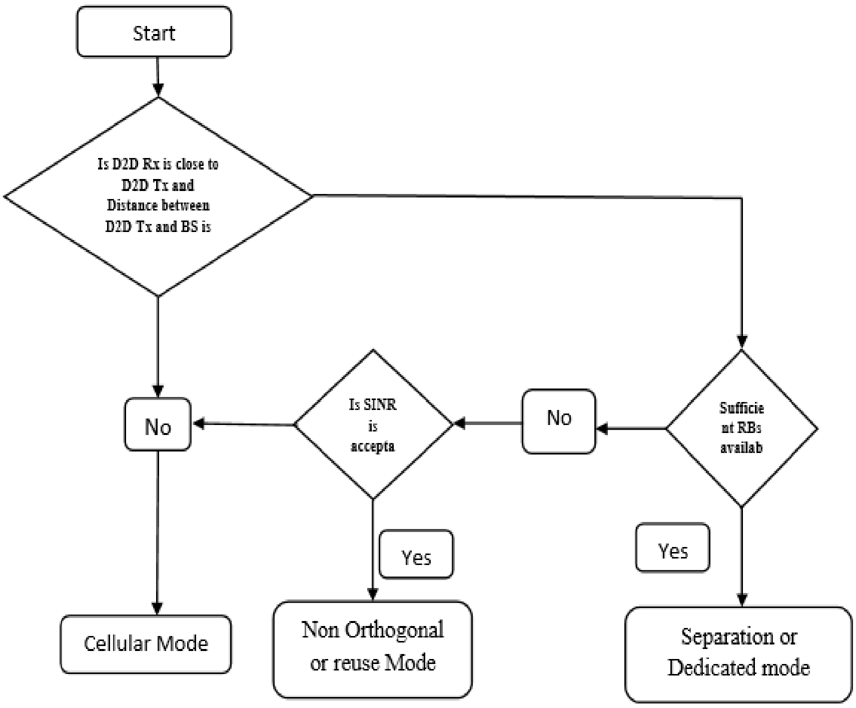

Fig.4. Flow chart of mode selection based resource allocation technique.

Third most important research challenge in two tier cellular architecture is to design of appropriate pricing model. Operator control scenarios e.g. OCDR and OCDC as discussed in section-III, allows base station to decide resource allocation policies and pricing strategies. An incentive based approach is preferable in this regard. According to this approach, incentives will be provided to UEs which will act as a relay node and provides data offloading services to other UEs. Incentive can be given inform of additional bandwidth, additional loyalty services and concession on monthly bill. This technique will encourage more no of UEs to be participated in D2D communication and hence increase profitability of the operator. A utility function can be defined for OCDR scenario as [12], U=B $\log_2 (1+x\ \gamma)$-H B P+$\overline{B} \log_2 (1+ x\ \overline{\gamma})$, Here, B is the BS to UE-A link bandwidth. x is defined as spectral efficiency. γ is signal to noise ratio. The first term of this equation i.e. B $\log_2 (1+x\ \gamma)$ provides the revenue of UE-A. Second term of the equation i.e. HBP describes the charges that need to pay to the operator. H is defined as total no of hops between base station and relay node.

IV. Conclusion

In this article, we have envisioned two tier cellular architecture and various technical challenges associated to it. Resource allocation, interference control, service discovery protocol design and pricing model has been discussed in a precise form. It also proposed incentive based spectrum sharing concept which will encourage the participation of mobile user equipments (UEs) and increase the profitability of operators. The paper insights recent technical updates of 3GPP releases and feasibility study of D2D communication in fifth generation wireless system.

References

[1] A. Gupta and R. K. Jha, “A Survey of 5G Network: Architecture and Emerging Technologies,” IEEE Access, vol. 3, pp. 1206–1232, July 2015.D. Astely et al., “LTE Release 12 and Beyond,” IEEE Commun. Mag., vol. 51, pp. 154–60, Aug. 2013.

[2] Udit Narayana Kar and Debarshi Kumar Sanyal, “An overview of device-to-device communication in cellular networks”, ICT Express, vol. 4, pp. 203–208, Feb. 2018.

[3] C. Hoymann et al., “Relaying Operation in 3GPP LTE: Challenges and Solutions,” IEEE Commun. Mag., vol.50, pp. 156–62, Feb. 2012.

[4] M.N. Tehrani, M. Uysal, H. Yanikomeroglu, “Device-to-device communication in 5G cellular networks: challenges, solutions, and future directions, IEEE Commun. Mag. vol.52, pp. 86–9252, May 2014.

[5] E. Hossain, M. Rasti, H. Tabassum, and A. Abdelnasser, “Evolution toward 5G multi-tier cellular wireless networks: An interference management perspective,” IEEE Wirel. Commun. vol. 21, no. 3, pp. 118–127, Jun. 2014.

[6] A. Gjendemsjo, D. Gesbert, G. E. Oien, and S. G. Kiani, “Binary power control for sum rate maximization over multiple interfering links,” IEEE Trans. Wirel. Commun. vol. 7, no. 8, pp. 3164 - 3173, Aug. 2008.

[7] B. Zhou, H. Hu, S. Q. Huang, and H. H. Chen, “Intracluster device-to-device relay algorithm with optimal resource utilization,” IEEE Trans. Veh. Technol., vol. 62, no. 5, pp. 2315 - 2326, Jan. 2013.

[8] M. Hasan, E. Hossain, and D. I. Kim, “Resource allocation under channel uncertainties for relay-aided device-to-device communication underlaying LTE-A cellular networks,” IEEE Trans. Wirel. Commun., vol. 63, no. 10, pp. 3882 - 3897, Aug. 2014.

[9] Z. Lin, L. Huang, Y. Li, H. C. Chao, and P. Chen, “Analysis of transmission capacity for multi-mode D2D communication in mobile networks,” Pervasive Mob. Comput., vol. 41, pp. 179–191, Oct. 2017.

[10] H. Min, W. Seo, J. Lee, S. Park, and D. Hong, “Reliability improvement using receive mode selection in the device-to-device uplink period underlying cellular networks,” IEEE Trans. Wirel. Commun., vol. 10, no. 2, pp. 413–418, Dec. 2011.

[11] N. T. Nguyen and K. Lee, “Cell Coverage Extension with Orthogonal Random Precoding for Massive MIMO Systems,” IEEE Access, vol. 5, pp. 5410–5424, Apr. 2017.

[12] E. Hossain, D. Niyato, and Z. Han, “Dynamic Spectrum Access and Management in Cognitive Radio Networks”, 1st ed., Cambridge Univ. Press, 2009.