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Device-to-Device Communication: A Primer

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Abstract The wireless technology is increasingly being adopted and integrated into the fabric of our daily life. At the moment, the number of wireless hand-held devices is radically increasing, with a corresponding rising demand for higher data rate applications. In order to meet the needs of the next generation applications, the fifth generation (5G) networks are expected to fulfill these demands. Device-to-device (D2D) communication is an indispensable component of 5G networks. D2D communication is an emerging cellular technology which allows communication between two devices, without the participation of the base station. This paper provides a brief introduction to D2D communication.

Keywords Device-to-device communication, cellular network, 5G, smart device to smart device communication

Introduction

Wireless communication networks have witnessed rapid changes, a tremendous growth, and skyrocketing consumer demand in the past decades. The huge demand for mobile multimedia has presented unprecedented challenges to the networking community. The growing demand has led to the evolution of cellular communication networks from the first generation (1G) to the fifth generation (5G). Due to the drastic increase in the number of wireless devices, the channels available in a cell become insufficient and need to be flexibly used. The current wireless technologies are not capable of accommodating the exponential growth rate and bandwidth demand.

In a traditional cellular network, all communications must go through the base station (BS)(or access point) even if communicating users are in close proximity. In cellular networks, device-to-device (D2D) communication is direct communication between two mobile partnerswithout going through the BS [1]. Communication through BS suits low data rate mobile services such as voice call and text messaging in which users are seldom close enough for direct communication. However, mobile users in today's cellular networks use high data rate services (e.g., video sharing, gaming, proximity-aware social networking) in which they could be in range for direct communications [2]. D2D enables two cellular user equipment (UEs) in proximity to communicate with each other directly (and bypassing the BS) in cellular spectrum by establishing direct links. Such a direct transmission improves spectral efficiency and reduces latency.

Concept of D2D Communication

Wireless networks have evolved from first generation (1G) to fifth generation (5G), as illustrated in Figure 1 [3]. The first four generations of cellular networks have been network centric, but 5G is heading towards device-centric network architecture in which network is managed by the devices themselves and the user performs storage, relaying, computation and content delivery, which was earlier being performed by BS. 5G technology is expected to bring dramatic improvements from the large scale data transmission to latency, from reliable data transmission to energy efficiency.

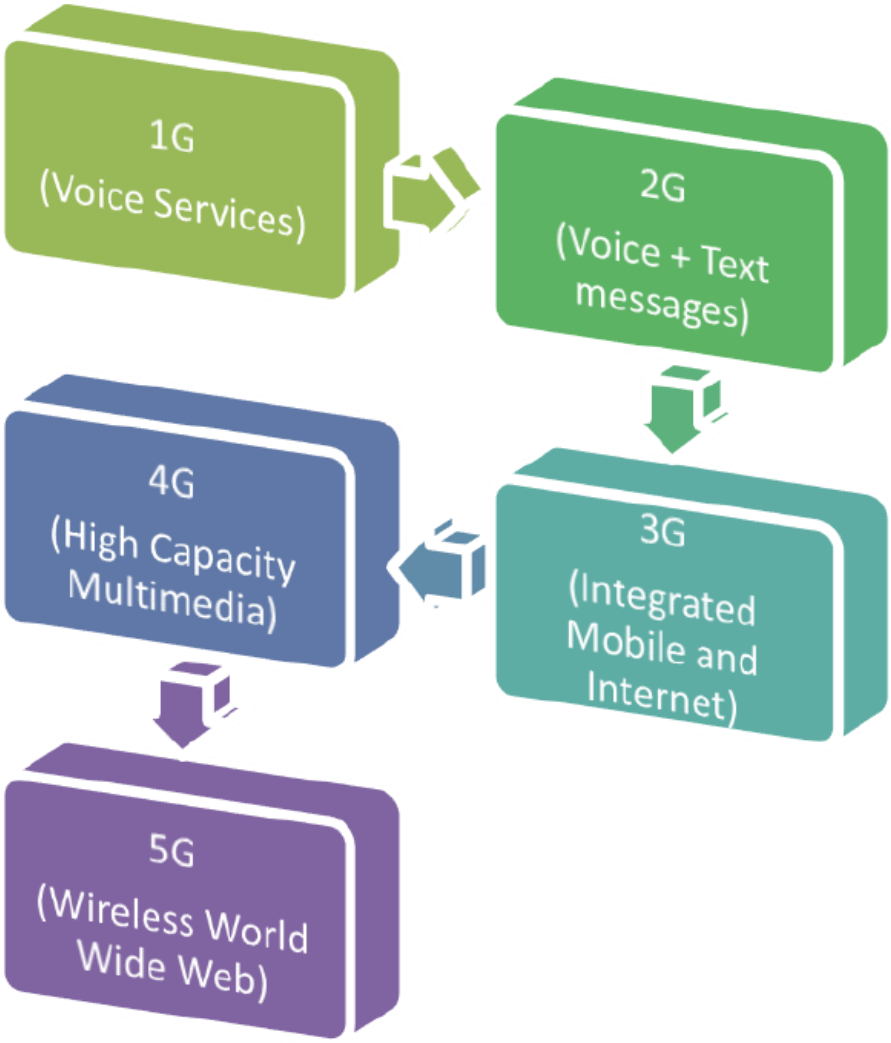

Figure 1: Generations of wireless communication [3]

A key technology of the 5G networks is device-to-device (D2D) communication. In D2D communication, two devices that are close to each other can communicate directly through a direct link without the participation of the base station. Figure 2 shows a typical **c**ellular communication and D2D communication [4]. D2D communication can be used with other technologies like cooperative communication, cognitive radio, and Internet of things (IoT) [5]. D2D in cellular network has the following expectations: (1) Enhanced system capacity, (2) Increased spectral efficiency, (3) Better throughput, (4) Better network performance, (5) Reduced Latency, (6) Expansion of coverage, (7) Low traffic and low congestion.

As shown in Figure 3, D2D communication may use the licensed spectrum (in band) or the unlicensed spectrum (out band) for direct link formation [6]. For inband case, D2D links can reuse cellular resources(i.e. *underlay*) causing D2D-cellular interference or D2D links can use dedicated cellular resources (i.e. *overlay*) to avoid interference. Services associated with D2D communication include mobile cloud computing, cellular data offloading, and disaster management.

One key feature of D2D communication is cooperative communication. In this type of communication, devices act as relays to extend cell coverage. This is a focal technology in the cellular networks today. Cooperation is based on social reciprocity and trust.

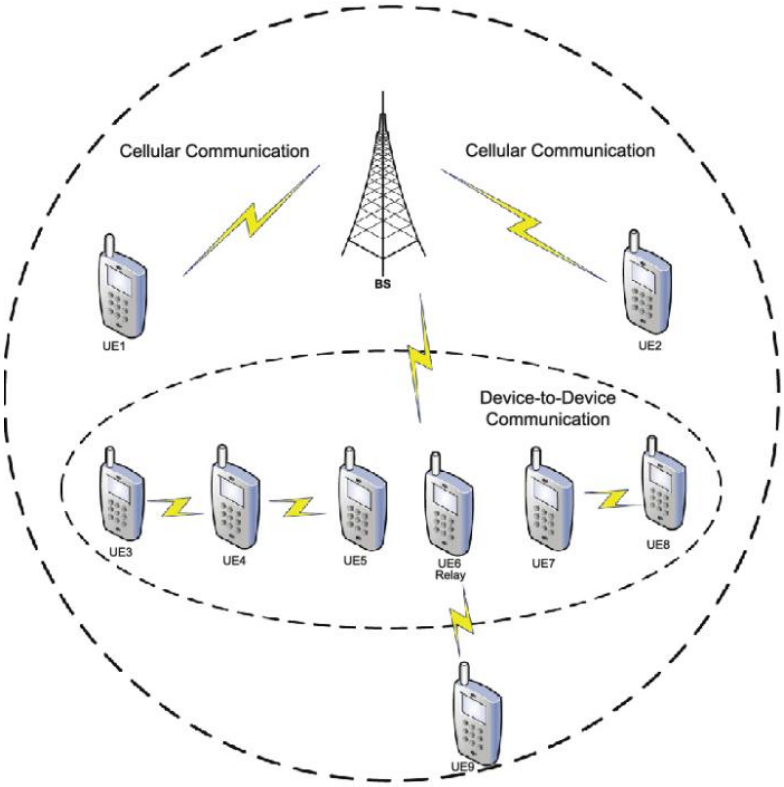

Figure 2: Typical cellular communication and D2D communication [4]

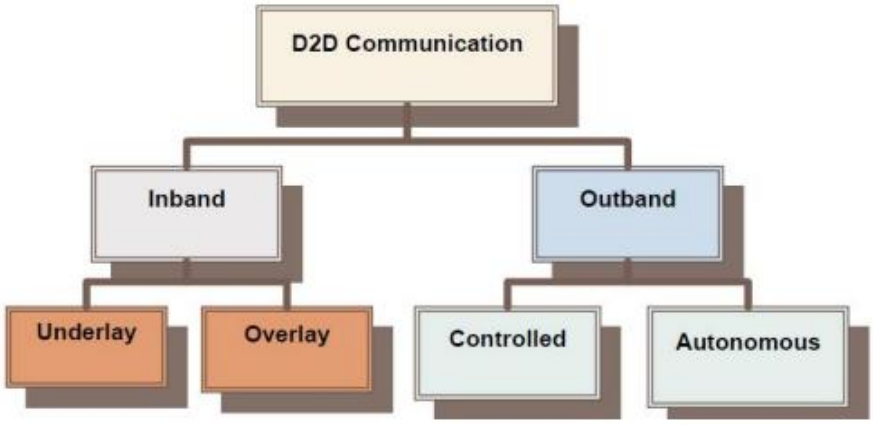

Figure 3: Two types of D2D communication [6]

Applications of D2D

Wireless communication can be achieved not only through cellular networks but also opportunistic device-to-device (D2D) communications. Unlike conventional cellular network, D2D allows proximity users to communicate directly with each other without routing the data through a base station. D2D networking opens up new opportunities for proximity-based commercial services, particularly social networking applications, public safety, local data transfer, and data flooding. D2D communication will play a significant role in upcoming cellular networks as it promises ultra-low latency. Its applications include multicasting, video dissemination, M2M communication, location-aware services, social networking, and smart grids. M2M communications will be highly benefitted by D2D communication. Figure 4 depicts some representative applications of D2D communication [7].

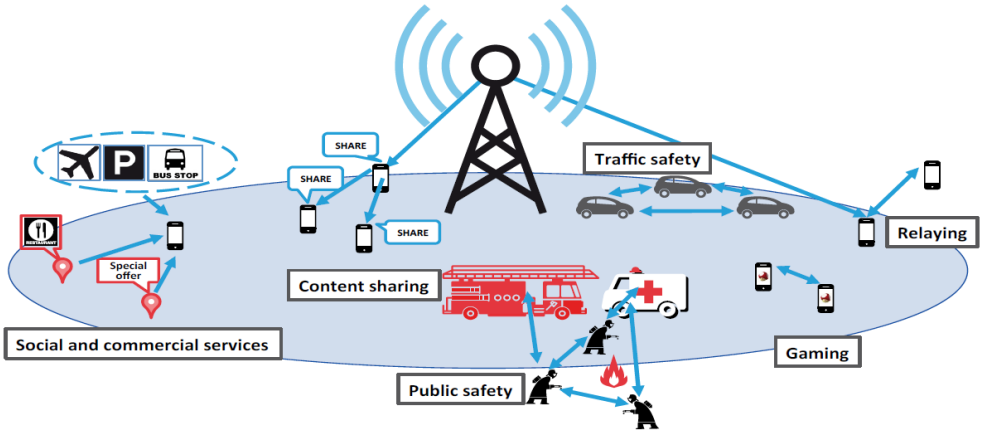

Figure 4: Representative applications of D2D communication [7]

- *IoT Enhancement:* Since devices will be the main users in the Internet of things (IoT) ecosystem, device-to-device (D2D) communication is expected to be an intrinsic part of the IoT. D2D communication in conjunction with IoT results in a massive interconnected wireless network which can support numerous applications. A typical application for such a scenario is vehicle-to-vehicle (V2V) communication, in the Internet of vehicles (IoV) [8]. IoT requirements to connect anything, anytime, and anywhere, builds a bridge between the real world and the digital world.
- *Proximity Services*: In proximity or local service, user data is directly transmitted between the terminals and does not involves network side. Examples of social proximity services include social networking, gaming, content sharing, smart cities, machine-to-machine (M2M) communications, personalized services, vehicle-to-everything (V2X) communications, and video distribution.
- *Public Safety Services*: Direct communications can be setup between mobile users based on D2D communications in order to assure public protection, disaster relief, and public safety services. In case of natural disasters (hurricanes, earthquakes etc.), the traditional communication network may be damaged. Ad-hoc network can be established via D2D.
- *Social and Commercial Services:* D2D communication is a promising technology to support the increasing demands for content sharing. Examples include communications within the same neighborhood using social networking applications, sharing of multimedia files between trusted users in close proximity.

Benefits and Challenges

D2D communication is regarded as an important emerging technology for present and future cellular networks with several benefits to both mobile users and network operators. It allows peer-to-peer communication between users, enhancing the spectrum utilization with better network performance, improved spectral efficiency, energy efficiency (low energy consumption), and system throughput. Other benefits include its ability to off-load traffic from cellular network without using an alternative radio access technology, its direct link supporting high data rate, its low power to conserve battery lifetime, and its ability to connect even during network congestion. D2D communication is one of the promising technologies designed to meet the technical goals of the next generation networks (NGNs).

Despite the numerous benefits offered by device-to-device (D2D) communication, its implementation faces a number of challenges. Challenges of D2D communication in wireless networks include [4]:

- *Synchronization:* Synchronization among UEs is beneficial for D2D communication because it helps a UE to use the right time slot. D2D communication often requires more accurate synchronization and also allows more complex algorithms.
- *Peer discovery*: In setting up D2D links, pairing UEs that are in close proximity is essential. This is accomplished through neighbor or peer discovery. The neighbor or peer discovery is the problem of

devices identifying other devices which they can communicate to effectively, i.e., those devices whose signal can be received with a power great enough.

- *Resource allocation:* Radio resource allocation is important in creating and maintaining direct links between D2D pairs in a cellular network. It is a process of allocating voice and data channels to their respective users. It is a major detriment in D2D communication.
- *Interference management:* Integration of D2D technology with cellular networks results in interference due to the sharing of same resources. Cellular and D2D links may interfere with each other based on how they share the frequencies. D2D links suffer interference from each other as well as from other devices operating in the same frequency band.
- *D2D with mobility:* Mobile users in current cellular networks use high data rate services in which they could potentially be in range for direct (D2D) communications. Dealing with non-cooperative mobile nodes is challenging due to the distributed network model and intermittent access of nodes to central authorities.
- *Security:* Wireless channels are broadcast in nature. As a result, they are susceptible to a number of attacks, making security an important issue. Since data is not stored at a central location, D2D links can be paralyzed by common attacks like eavesdropping, denial of service, man-in-the-middle, node impersonification, IP spoofing, malware attack, etc. Lack of a central authority makes it difficult to implement security and privacy measures.
- *D2D and 5G:* The fifth generation (5G) network is essentially an aggregation of a number of technologies such as mm-wave communication, massive MIMO, and cognitive radio networks. It is expected to support aggregate data rates. The evolution of wireless networks towards 5G has made D2D to become an integrative term of emerging technologies that take advantage of the proximity of communicating entities in licensed and unlicensed spectra. The key expectations of 5G networks are: high minimum throughput (almost 50Mbps), high capacity and data rates (×3 spectral efficiency compared to 4G), high reliability (up to 10−6), low latency (1 to 10 ms latency), high energy efficiency (energy consumption divided by 2) etc. [8]. Designing wireless networks which fulfill these ambitious specifications, while taking into account constraints cost, energy, and radio spectrum, is very challenging.

Conclusion

D2D is one of the key technologies for the next generation cellular systems. It allows proximate devices to directly communicate with each other by establishing direct links. D2D communication is an exciting and innovative feature of next-generation cellular networks.

It utilizes mobile devices located within close proximity for direct connection and exploits the opportunistic context of the devices in order to create a more powerful infrastructure. D2D communication underlaid over cellular systems has recently emerged as a promising technique that can significantly boost the performance of cellular networks in terms of spectral and energy efficiency. It can potentially improve network congestion, improve network capacity, coverage, and robustness, enable new services, etc. For more information about D2D communications, one should consult the books in [9,10].

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