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Underlay D2D in mobile and wireless networks

ABSTRACT

Device-to-Device (D2D) communication as a new technology bring many advantages for mobile and wireless networks. Higher spectral efficiency for the LTE advances network such as wireless peer-to-peer services and higher spectral efficiency and as one of promising techniques for the 5G wireless communications system used as network traffic offloading, public safety, social services and applications such as gaming and military applications [1].

As newer and more demanding applications arise and subscriber base increase exponentially, more novel techniques to boost data rates and reduce latency is required [2]. 5G has a broad vision and envisages design targets that include 10-100 x peak rate data rate, 1000 x network capacity, 10 x energy efficiency, and 10-30 x lower latency. These technologies affect all aspects of radio access network and applications: from wireless network infrastructure and topologies to physical layer transmission techniques, including spectrum availability, channel modeling, device innovations, and green radio [3].

Due to configuration complexity current ad-hoc mode of communication does not give potential to operators to offload traffic the from core network and the framework for a new communication paradigm [3]. Lte-A, Qualcomm and IEEE 802.15.4g(SUN) are addressing the standard of D2D communication over licensed band and a breakthrough was achieved in due course when 3GPP (LTE-A release, 12 June 2012) agreed on starting a study item for D2D technology.

This report is a review of some important aspects in architecture of D2D cellular network specifically underlay D2D and challenges that addressed in papers and researches.

1.INTRODUCTION

In recent years, high growth rate of wireless communication and data traffic, increasing demand for broadband mobile wireless communications, applications and services constituted the key drivers to the development of the Long term Evolution-Advances (LTE-A) Network [1]. One of the main Challenges of LTE-A is to recover the local-area services and enhance spectrum efficiency. Device to Device (D2D) communications is new technology that offer wireless peer-to-peer services and improve spectrum utilization in LTE-A network to enhance network performance [1].

Also, 5G is considered to be convergence of Internet services with existing mobile networking standards leading to the commonly used term “mobile internet” over heterogeneous networks (HetNets), with very high connectivity speeds [3]. D2D allows user equipment’s (UEs) in close proximity to communicate using a direct link rather than having their radio signal travel all the way through the base station (BS) or the core network. Various short-range technologies like Bluetooth, WiFi-Direct and LTE Direct can be used to enable D2D communication by providing ultra-low latency in communication due to shorter signal traversal path differ mostly in data rates, distance between 1-hop devices, device discovery mechanisms and typical applications [2]. Also, it has significant role for achieving established standards of 5G communication due to its ability of resource sharing [4].

From a technical perspective, exploiting the natural proximity of communicating devices may provide multiple performance benefits [5]:

1- D2D user equipment (UE) may enjoy high data rates and low end-to-end delay due to the short-range direct communication.
2- it is more resource-efficient for proximate UE devices to communicate directly with each other than routing through an evolved Node B (eNB) and possibly the core network. compared to normal downlink/uplink cellular communication, direct communication saves energy and improves radio resource utilization.
3- switching from an infrastructure path to a direct path offloads cellular traffic, alleviating congestion, and thus benefitting other non-D2D UE as well.

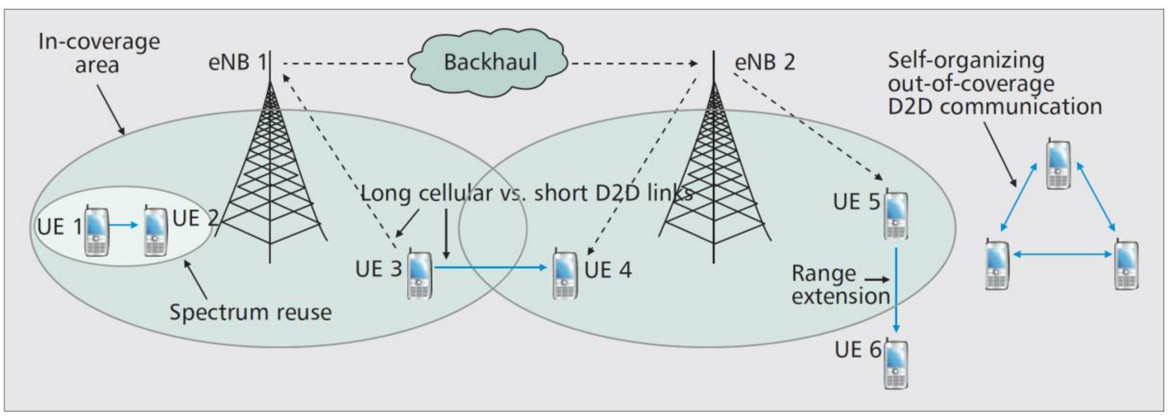

Figure 1 Illustration of possible D2D use cases and potential benefits [5].

2. D2D Standardization Activities and History

In earlier studies D2D was mainly proposed for relaying purposes [6] [7], allowing radio signals to be relayed by mobiles in cellular networks, it was shown that the coverage and throughput performance can be improved [6] [7]. D2D in cellular networks has been motivated by the trend of proximity-based services and public safety needs [8]. Increasingly network operators and device manufacturer agreed on D2D communications as the future of 5G, which caused the standardization of D2D technologies.

At the 3GPP meeting held in June 2011, the concept of D2D discovery and communication was submitted by Qualcomm. Meanwhile, in the 3GPP meeting held in August 2011, a study item description on LTE Direct (LTE-D) was submitted proposing the study of the service requirement for direct over-the-air LTE D2D discovery and communications. Furthermore, main results on D2D use cases and potential requirements for a network operator controlling discovery and communications between nearby devices were studied in the meeting of November 2011. Towards the finalization of LTE Release-11, 3GPP initiated the agenda for Release-12, which was initiated at a workshop in June 2012. At that workshop, it was agreed that machine type and short-range communication scenarios can be embraced to accommodate new traffic types. Subsequently, the radio access network (RAN) 58th plenary meeting held in December 2012 agreed to start the study of LTE D2D proximity service (ProSe). The study on ProSe includes two parts, namely D2D discovery and D2D communication. The study on LTE D2D ProSe mainly focuses on technical details, such as discovery signal design, resource allocation and scheduling, synchronization mechanism, channel models, etc. [9].

3. Classifications of D2D Communications

Generally speaking, D2D users can communicate with each other in three manners [9]:

- ***D2D Direct Link***: The simplest case of D2D communication occurs when transmitters and receivers exchange data directly with each other without intermediate nodes.
- ***Relay Assisted D2D Communications***: Given a scenario where a mobile device wants to connect to another node which is out of its communication coverage or is in a poor channel state with the destination node, cellular users may be employed as relays to improve the data transmission between transmitters and receivers.
- ***Clustering-Based Communications***: In a content sharing or information diffusion scenario, users requesting the same file in a short range can potentially form a cluster to allow the desired file to be multicasted within the cluster to save both bandwidth and time delay. Moreover, users with similar interests or with tight social relationship (as illustrated by the tendency to "follow" one another) can also form a cluster to share contents with one other via D2D communications.

Both unlicensed and licensed spectrum resources can be occupied by D2D users for communication [9], based on which D2D communications divided into outband D2D communications and inband D2D communications.

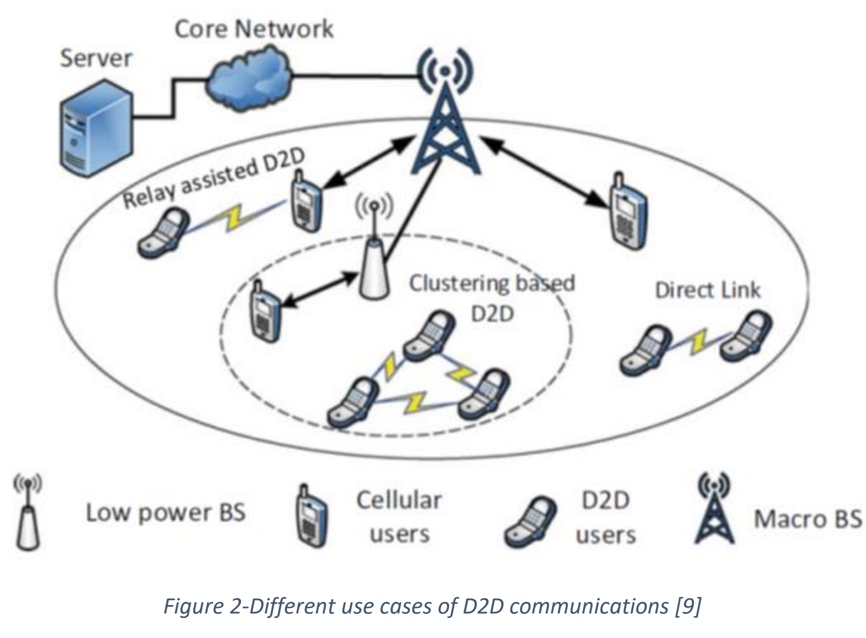

Figure 2-Different use cases of D2D communications [9]

Outband D2D: As shown in the left side of Fig.2. Key advantages of outband D2D communications lie in the absence of interference between D2D links and cellular links since D2D communications occur on license-exempt bands [9]. In this category, D2D communication is performed in the unlicensed spectrum such as ISM 2.4G which made the interference between D2D and cellular communications impossible. On the other hand, Outband D2D may suffer from the uncontrolled nature of unlicensed spectrum [1]. To exploit the unlicensed spectrum, it is necessary to have another extra interface that implements WIFI Direct, Zig Bee or Bluetooth. Outband D2D can be generally divided into controlled and autonomous communications [9]. In autonomous outband D2D communications, the cellular network controls all the communications but leaves D2D communication to the users themselves (extra interface/technology) while in controlled outband D2D communications, coordinations between radio interfaces is controlled by cellular network [9].

Inband D2D: In this category, D2D communications operate on licensed spectrum (i.e., cellular spectrum) which is also allocated to cellular links [9]. Motivation for choosing inband is usually high control over cellular (i.e., licensed) spectrum as uncontrollable interference in unlicensed spectrum which add constraints for QoS provisioning [10]. Inband D2D communications devided into two types, underlay D2D communications and overlay D2D Communications. In underlay D2D communications DUEs share the same spectrum resources with some other cellular user equipment CUEs [9] which improve spectrum efficiency and network throughput which are two important performance indices.

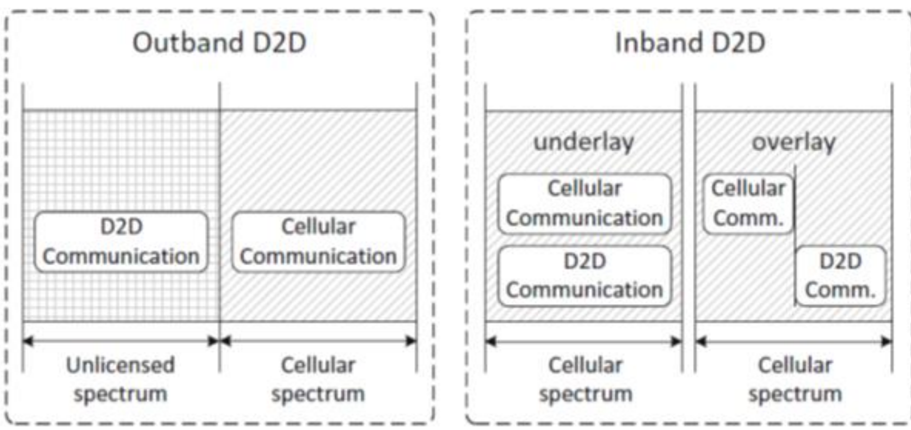

Figure 3-Outband D2D: D2D communications under this category exploit unlicensed [9]

4. Advantages and disadvantages of the different types of D2D communications

With the arrival of new smartphones and new mobile devices in phone market, device will be capable to implement Outband D2D schemes. Some researchers provide an overview of the advantages and disadvantages of Outband D2D communication. They are putting high hopes and are seeing it as the alternative to inbnd D2D communication category [1].

The majority of the literature on D2D communications propose to use the cellular spectrum for both D2D and cellular communications (i.e., *underlay inband* D2D). These works usually study the problem of interference mitigation between D2D and cellular communication [10].

A brief look of advantages and disadvantages of of Inband D2D and Outband D2D communications are given in the following tables [1]:

Table 1. Advantages and disadvantages of Inband D2D communication

Advantages of Inband D2D	Disadvantages of Inband D2D
• Underlay D2D increases the spectral efficiency of cellular spectrum by exploiting the spatial diversity. • QoS management is easy by reason of entirely controlled by eNBs. • The possibility of using Inband D2D communication on any mobile equipment.	• Challenging control of level of interference. • No possibility for D2D and cellular simultaneous transmission. • High complication of resource allocation procedure and power control

Table 2.Advantages and disadvantages of Outband D2D communication

Advantages of Outband D2D	Disadvantages of Outband D2D
• Easier resource allocation. • Possibility of simultaneous occurrence of D2D and cellular users. • None interference between D2D and cellular subscribers. • None necessary to devote cellular resources to D2D spectrum	• Necessary to decode and to encode packets. • D2D communication only used by LTE and WiFi radio interfaces. • Need of the efficient power management.

5.Critical Technologies for D2D Communications

5.1 Proximity Discovery

With proximity discovery or D2D discovery, users can discover other users that are in the proximity. Using E-UTRA, this process identifies that a UE is in proximity of another [1]. The D2D discovery can be initiated either before the DUEs start to communicate (labeled as "priori") or during ongoing communication (known as "posteriori") [11]. In priori, a user initiates the discovery process by broadcasting beacon signals at regular intervals, prior to the actual communication session between the users. While in the latter, a discovery process is initiated by the eNB, while a communication session is ongoing between users. In such case, the eNB identify the users as potential D2D pairs, by analysing their IP addresses, and therefore, recommend them to switch over to D2D mode, so as to achieve better performance and higher gain. In both cases, the eNB reserves a discovery resource pool, which is utilized for D2D discovery purposes [12].

FlashLinQ takes advantage of OFDM/OFDMA technologies and distributed scheduling to create an efficient method for timing synchronization, peer discovery, and link management in D2D-enabled cellular networks. In addition to academia and telecommunication companies, 3GPP is also investigating D2D communications as Proximity Services (ProSe) [10].

Generally, existing proximity discovery approaches for D2D communications can be classified into two types:

- **Distributed Approaches:** In this category, UEs broadcast their identities periodically so that other UEs may be aware of their existence and decide whether to start D2D communications or not. This approach is distributed and does not need the involvement of the BS. Distributed proximity discovery approaches are flexible, but time and energy consuming, employing beacon signals and sophisticated scanning [9].
- **Network-Assisted Approaches:** In network-assisted proximity discovery, pairable D2D UEs detect and identify each other with the assistance of the network. One UE informs the BS about its intension to communicate with another partner UE and transmits its own beacon signal. Then the BS executes message exchanges to acquire the identity and information about the potential link. This approach can be either *centralized* or *semi-centralized*, depending on the involvement of BS during the procedure of proximity discovery [9].

5.2 Procedure of Proximity Discovery

In centralized network-assisted proximity discovery, where BS coordinates all the messages in every step, UEs transmit or listen only upon request from the base station [9]. As shown in Fig. 4, the procedure of centralized network-assisted proximity discovery can be described as:

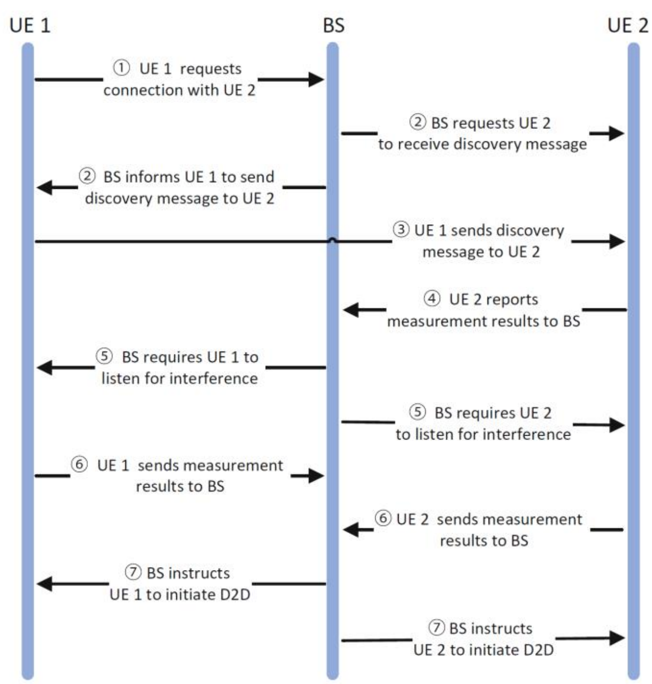

Figure 4- Centralized proximity discovery procedure

Step 1: UE 1 informs the BS about its intention to communicate with UE 2;

Step 2: BS requests UE 2 to expect a discovery message from UE 1, and UE 1 is informed to send the discovery message;

Step 3: UE 1 sends discovery message to UE 2;

Step 4: UE 2 reports the measured signal-to-interference-plus-noise ratio (SINR) value of the message transmitted by UE 1 to the BS;

Step 5: BS requires both UE 1 and UE 2 to listen for interference from existing users in the cell;

Step 6: UE 1 and UE 2 report to the BS their measured results of interference;

Step 7: BS instructs UE 1 and UE 2 to communicate with each other via D2D link if the direct link between UE 1 and UE 2 is favorable.

In semi-centralized proximity discovery, the role of the BS is less dominant since the initial steps of the procedure do not include message transmissions with the BS [9]. As shown in Fig. 5, the procedure of semi-centralized proximity discovery can be described as:

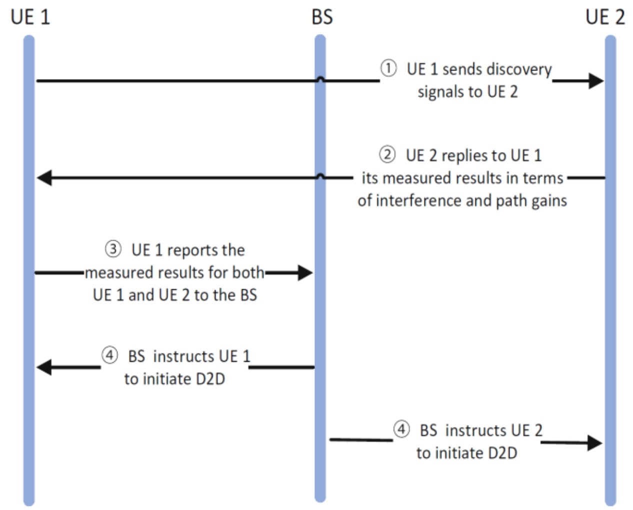

Figure 5- Semi-centralized proximity discovery procedure

Step 1: UE 1 sends discovery message to UE 2 without requesting permission from the BS. Both UE 1 and UE 2 listen for interference from the other users in the cell and estimate their path gains to the BS immediately upon the reception of the message sent by UE 1 to UE 2;

Step 2: UE 2 reports its measured results to UE 1 in terms of the interference it suffered and its path gains to the BS;

Step 3: UE 1 feeds back to the BS about the SINR and interference measurements for both UE 1 and UE 2;

Step 4: BS requests both UEs to initiate D2D communications.

li Wang in [9] mentioned some other location-based D2D discovery schemes and beacon-based D2D discovery schemes. Location-based proximity discovery exploits wireless localization methods, e.g., angle-of-arrival (AOA), time-of-arrival (TOA), time-difference of-arrival (TDOA), and global positioning system (GPS), to track the location of each UE.

Authors in [1] review and categorized some more different methods for proximity (peer) discovery in D2D communication networks which listed in below table as well.

Table 3-Different methods of peer discovery for D2D communication and their comparison [13]

Technique for device discovery	**Objectives**			
	Easy discoverability	Reduced latency	Energy efficiency/ power efficiency	Throughput enhancement
Restricted or Open Discovery	✗	✓	✗	✗
Energy-efficient device discovery	✗	✗	✓	✗
Sound Referencing Signal for neighbor Discovery	✓	✓	✗	✗
• Bluetooth Discovery • WiFi Device Discovery • WiFi Direct Device Discovery • IrDA Device Discovery • Network Assisted Discovery • Packet and Signature-based Discovery • Request Based Discovery • Direct Discovery	✓	✗	✓	✗
Network Assisted Discovery Technique	✓	✗	✗	✗
Bio-inspired Proximity Discovery	✓	✓	✗	✗
Network assisted proximity discovery	✗	✓	✗	✓
Time Advance proximity discovery	✓	✗	✓	✗

5.3 Mode Selection

D2D communications have the potential to achieve performance gain over traditional cellular communications in terms of bandwidth, time delay and power. It does not mean that it is always optimal for UEs to work in D2D mode from the performance perspective [9]. More sophisticated objectives like optimal spectrum reuse, weighted sum-rate maximization, etc. could also be used [2]. In [10] they addressed different kind of techniques and algorithms which used in spectrum efficiency and power efficiency for mode selections like heuristic or statistical ones.

Proper mode selection plays a crucial role in D2D communication. The reason is that it determines the potentials to increase the frequency reuse factor (spectral efficiency of the system) and, at the same time, it affects the amount of interference among the CUEs and the DUEs (or among the DUEs) [13]. In [13] they categorized mode selection as *Static* and *Dynamic* and they have intensive review of different techniques and algorithms looking to different aspects and various metrics such as distance, channel quality of D2D and cellular links, interference, load of the eNB, and energy efficiency.

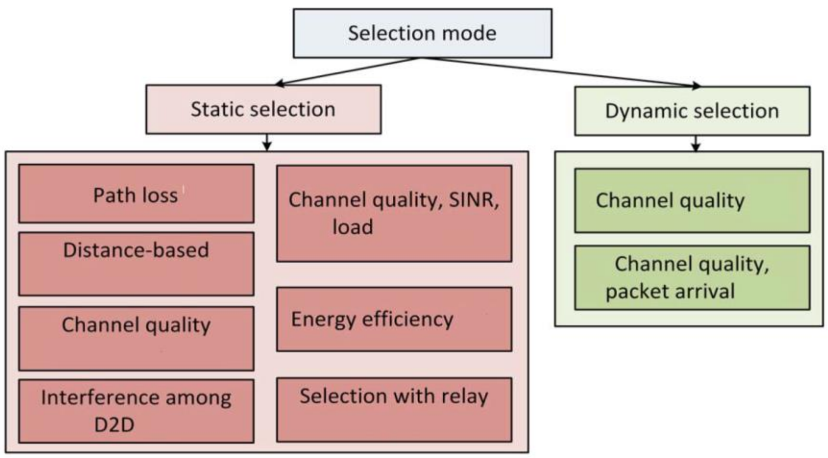

Figure 6-Overview of mode selection techniques for D2D communication [13]

5.3.1 Taxonomy of Typical Communication Modes

Basically, UEs can work in one of the four modes as illustrated in Fig. 7.

D2D Silent Mode When available resources are not enough for D2D communications with dedicated resources, and spectrum reuse is impossible either owing to harmful interference, D2D users are incapable of data transmission and have to keep silent [9].

D2D Reuse Mode UEs communicate directly via D2D links by sharing the uplink or downlink spectrum resources of CUEs in cellular D2D underlay [9].

D2D Dedicated Mode Dedicated cellular spectrum resources are allocated for UEs to communicate directly via D2D links [9].

Cellular Mode In this mode, two UEs can communicate with each other through the BS without co-channel spectrum sharing in traditional way [9].

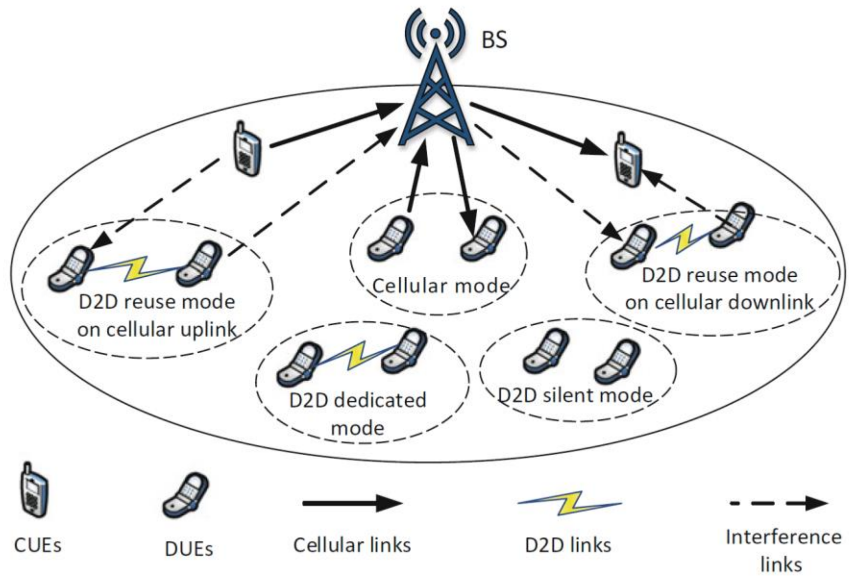

Figure 7- D2D communication modes [9]

5.4 Resource Management -Interference Management

During mode selection, resource management is usually implemented simultaneously to evaluate achievable performance when working on different modes. Regarded as one of the most critical issues in wireless networks, resource management can be carried out to facilitate interference mitigation, energy conservation, and throughput maximization, among others [9].

Generally, resource management in network-assisted D2D communications mainly consists of two parts: *spectrum allocation* and *power control* [9].

5.4.1 Spectrum Allocation:

By exploiting the spatial diversity, underlaying inband D2D is able to increase the cellular spectrum efficiency. This can be done by proper interference management, mode selection, resource allocation and by using network coding [10]. In 3GPP LTE specifications, UEs are allocated with certain number of subcarriers for a predetermined amount of time duration, which are defined as physical resource blocks or PRBs. Each PRB occupies one slot in time domain and 180 kHz in frequency domain, i.e., 12 subcarriers with subcarrier spacing of 15 kHz. A PRB is the smallest unit of spectral resource that the BS can allocate. The allocation of cellular resources to the D2D communications is critical since the interference to other CUEs and DUEs should be kept below a certain level to guarantee QoS requirements. Usually, resource allocation is jointly considered with mode selection, to determine whether some dedicated PRBs or shared PRBs should be allocated to D2D communications. When DUEs communicate in underlay mode, it should be determined which CUE’s resource should be shared [9].

Main techniques used in literature for improving spectrum efficiency [10] namely are interference reduction among cellular and D2D users, interference aware/avoidance, self-organized methods(less overhead and are more efficient in comparison to network controlled methods). using advanced mathematical techniques, such as non-linear programming and game theory, can result in higher gain than simpler interference reduction/avoidance methods based on heuristics [10].

In [13] after device discovery there is three modes for resource allocation: cellular mode, dedicated mode, mode supporting reuse of resources of a single cellular user (CUE) and mode supporting reuse of resources of multiple cellular users. There is no interference problem in the first and second mode as they involve utilization of orthogonal resources, but these two modes maybe inefficient to maximize the overall network throughput [13]. Maximum resource utilization is achieved through reuse mode only, the other two mode have interference due to resource sharing. The radio resources are allocated using centralized or distributed techniques in D2D communication. Centralized techniques result in increased complexity in case of large networks, supporting a large number of UEs [13]. In these techniques of resource allocation, resources are allocated to the D2D users and cellular users by the base station (BS). Distributed techniques, on the other hand, decrease the device complexity, and reduce interference with the cellular networks [13].

In [13] authors reviewed different algorithms and techniques used for resource allocation in device-to-device (D2D) communication. Comparison of throughput from different algorithms in Fig.8

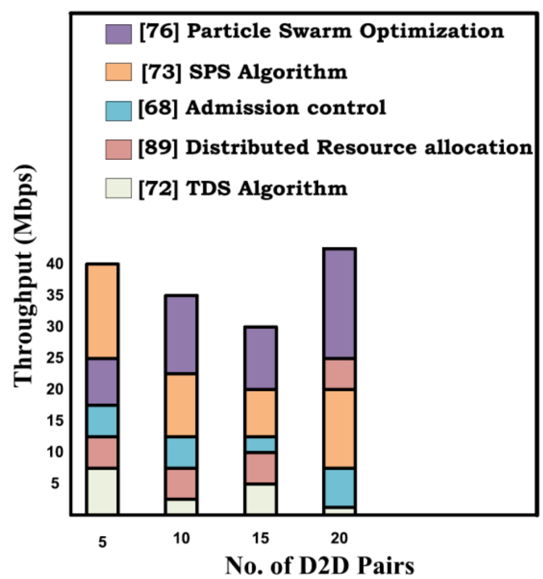

Figure 8-Comparison of Throughput of Different resource allocation algorithms [13].

5.4.2 power control:

controlling power of UEs is essential for efficient resource utilization. Blindly applying D2D communication to cellular networks can result in degradation of system performance [13]. Basically, transmit power of involved users should be controlled to guarantee QoS requirements (e.g., SINR requirements) of different users in the network [9].

Power control algorithms in D2D communication which reviewed in [13] are listed in below table:

Algorithm	Description	Objective
Game theory-based power control scheme	Stackelberg game model is used for selecting source and controlling the power	Improvement in the D2D transmission quality
Joint Power and Rate control for D2D communication in cellular networks	Maximize the sum rate of the cellular users in the network, guaranteeing Quality of Service (QoS) of D2D communication at the same time	Coexistence of both cellular and D2D userscontributing towards improving system throughput
Centralized and distributed power control algorithms using stochastic geometry	Centralized power control ensures sufficient coverage probability of cellular users and distributed method maximizes sum rate of D2D links	Improved throughput performance of cellular users achieved
Distributed Power Control Scheme	ALPF method is used , with optimal SINR target, to control the user equipment power	Minimize the overall power consumption of the network
Joint resource allocation and power control technique	Penalty function approach is adopted for power control in the network; the problem is formulated as a nonconvex optimization problem, and solved using a two-layer scheme	Maximizing energy efficiency of the network
Binary Power Control Scheme	A simple algorithm achieving near optimal utility , efficiently supporting a large number of D2D pairs in the cellular network	Improve spectral efficiency and power efficiency
Distance based mobile association Scheme	Access point selection, mode switching, relay selection and power control, all are considered and basis of this technique is the location of UEs in the network	Better tradeoff achieved between energy efficiency and complexity, in comparison to other techniques
Revised Graph coloring based pilot allocation	A fast converging algorithm proposed to overcome pilot contamination by limiting D2D transmission power. It is an optimal choice for practical considerations.	Considerable reduction in pilot overhead

Table 4-Power control algorithms in D2D communication

5.4.3 Interference control

In D2D communication in cellular networks resources are shared by D2D users, the cellular users and their neighbors. When the cellular downlink resources are shared by the D2D users, the cellular users and their neighbors suffer interference. The receiver of the D2D pair is also susceptible to counter interference by the base station. When sharing cellular uplink resources, the base station suffers interference by the D2D users [13]. Interference mitigation is possible through proper mode selection, optimum resource allocation and power control of the devices.

The various approaches for interference mitigation are categorized into three types [13]:

- **Interference Cancellation Techniques**, which use advanced coding and decoding methods for cancellation of interference signals at the CUE or DUE. Interference cancellation techniques have the ability to enhance the capacity of cellular networks.

- **Interference Avoidance Techniques**, which avoid interference between cellular links and D2D links by using orthogonal time frequency resource allocation techniques.
- **Interference Coordination Techniques**, which mitigate interference between D2D and cellular links with power control schemes and proper scheduling.

5.4.4 Joint Power Control and Radio Resource allocation Techniques

A more advanced approach for mitigating interference in D2D/LTE system is to jointly use power control with various resource allocation techniques in order to realize the full potentials of D2D communication [12].

Interference management and control between cellular links and D2D links, with the aim of complementing and enhancing the overall performance of a single scheme [12]

Combined effect of dynamic power control and resource allocation to reduce D2D interference to cellular network. The eNB initially assign resources to CUE, then to D2D users, and finally reuse CUE's resources to D2D users when the demand is high. Then, the eNB dynamically adjust the transmit power of the D2D transmitter by determining the channel gain between individual terminals, in order to avoid harmful interference when both D2D and CUE occupy the same resources [12].

Power control and distance–based resource allocation mechanism to mitigate the interference among cellular and D2D users sharing UL resources [12]

Interference avoidance model based on user location, rather than limiting the transmit power of D2D users as in conventional interference management scheme, an interference limited area is proposed. Within this area, no cellular user will share the same resources with a D2D pair. As such, excessive interference between D2D and cellular communication is avoided [12].

A power control and distance–based interference mitigation algorithms [12].

5.4.5 Spectrum Splitting Techniques

Spectrum splitting is the easiest way to avoid interference in D2D enabled cellular network. Adopting time division multiplexing (TDM) technology to separate cellular and D2D transmissions could effectively reduce the interference level in the hybrid cellular network with D2D communication [12].

5.4.6 Other Interference Mitigation Techniques

application of network coding technique: To mitigate the interfering D2D signals to eNB, helper nodes are selected to assist in cellular UL transmission to eNB, and network coding is applied for the actual transmission [12].

interference–aware interference mitigation algorithms in network-assisted D2D communication: the gain of interference–aware algorithms are evaluated using simultaneous non-unique decoding (SND) and decoding cellular interfering signals at the D2D receiver reduces interference [12].

5.4.7 Multiple-Input Multiple-Output Techniques

MIMO transmission methods such as beamforming, interference cancellation technique, can be utilize in D2D communication undelaying cellular communication to further avoid interference between cellular links and D2D links with the prior knowledge of the interfering channels CSI. the transmit power is maximized towards the receiver angle, while minimizing the signal in the null space. When transmitting, a beamformer controls the phase and relative amplitude of the signal at each transmitter, thereby producing a high directional beam pattern in the direction of the intended recipient and null in the direction of interference. This increases the SINR of the intended user and reduces the wastage of transmitted power in the undesired direction. Other benefits of beamforming include high spectrum reuse factor, increase in capacity, etc. Therefore, the use of such multi–antenna beamforming either at downlink or uplink transmission can mitigate the interference levels between cellular and D2D transmission, improves system capacity and further guarantee the feasibility of D2D transmission [12].

5.4.8 Comparative analysis of D2D Interference Mitigation Techniques

Most of the interference mitigation techniques for D2D enabled cellular network in the literature employs the PC, RRA, hybrid/joint and multi-antenna schemes. Other schemes proposed such as networking coding, spectrum splitting, etc., where not given considerate attention [12].

Majority of the RRA techniques employed; (1) channel sensing and (2) geographical user location–aware reuse approaches, to schedule cellular and D2D users efficiently, while avoiding interference in the cross-tier system. MIMO techniques are more promising and yield remarkable performance compared with other interference mitigation techniques. However, these MIMO schemes are yet to be exploited in the UL reuse direction [12].

Characteristics	**Power control**		**Radio Resource allocation**		**MIMO**
	Fixed	*Dynamic*	*Channel-based RA*	*Distance-based RA*	*Beamforming*
Target	Cellular QoS guaranteed, maximize throughput	Cellular QoS guaranteed, maximize throughput	Interference reduction, D2D capacity enhancement, improve SINR,	Interference reduction, D2D capacity enhancement, improve SINR,	Improve D2D link quality, interference avoidance, maximize total system throughput
Central Control	eNB	eNB	Depends on design requirement	Depends on design requirement	Depends on design requirement
Complexity/Cost	Low	High	High	Medium	High
Interference reduction level	Low	Low	High	Medium	High
Interference control type	Centralized	Centralized	Centralized	Centralized	Centralized/Distributed
Spectrum efficiency	Medium	Medium	Low	Low	High
Side information	Control Signals	Periodical CSI Feedback	Channel measurement and feedback	User location information via GPS	CSI
Flexibility	Fixed	Dynamic	Dynamic		

Table 5-COMPARATIVE ANALYSIS OF INTERFERENCE MITIGATION TECHNIQUES IN D2D COMMUNICATION [12]

Scheme	Pros	Cons
Power Control	• Transmission power can be optimized in an adaptive manner to suppress interference • Simple to implement, especially when the D2D pairs are in close range • Low computational cost	• Low probability of D2D communication between D2D pairs due to limited transmit power • Not effective in mitigating interference from cellular users to D2D users • Limited performance from D2D communication perspective • Unable to dynamically reflect channel variations, especially when fixed PC is employed
RRA	• Resource allocation algorithms can be optimized to suitably avoid interference • Fractional frequency reuse improves channel quality by utilizing different resources for D2D and cellular communication	• Inefficient utilization of the licensed spectrum • Requires channel statistics and exact knowledge of user location, which incurs additional signaling overhead to the eNB • Longer scheduling time due to large signaling overhead • Low throughput for high payload case • Computationally intensive when multiple D2D pair share the same resources with a cellular user
Joint PC and RRA	• Combines the advantages of PC and RRA	• Computationally intensive • Requires implementation of joint RRA and power algorithms • Increase in coordination and signaling overhead
Beamforming	• Robust interference mitigation solution • Directional beam targets the intended D2D recipient while creating a null towards other users	• Requires precoder design, which incurs computational overhead • Requires accurate CSI of all involved links • Cost of hardware (multiple antenna elements) implementation

Table 6- PROS AND CONS OF D2D INTERFERENCE MITIGATION TECHNIQUES [12]

6. Security in D2D

Combining user devices, protocols and network topologies in D2D communication and cellular networks as a single platform increase the risk of make the system vulnerable to different types of network attacks such as denial of service, man-in-the-middle, replay attacks, etc.

The security framework of D2D is categorized into two kind: *Open Access* and *Closed Access*.

Open Access: Any device in D2D mode is discoverable also any device can act as relay for all other potential devices in D2D mode.

Closed Access: to ensure levels a privacy the closed access provides list of trusted devices that can be discovered.

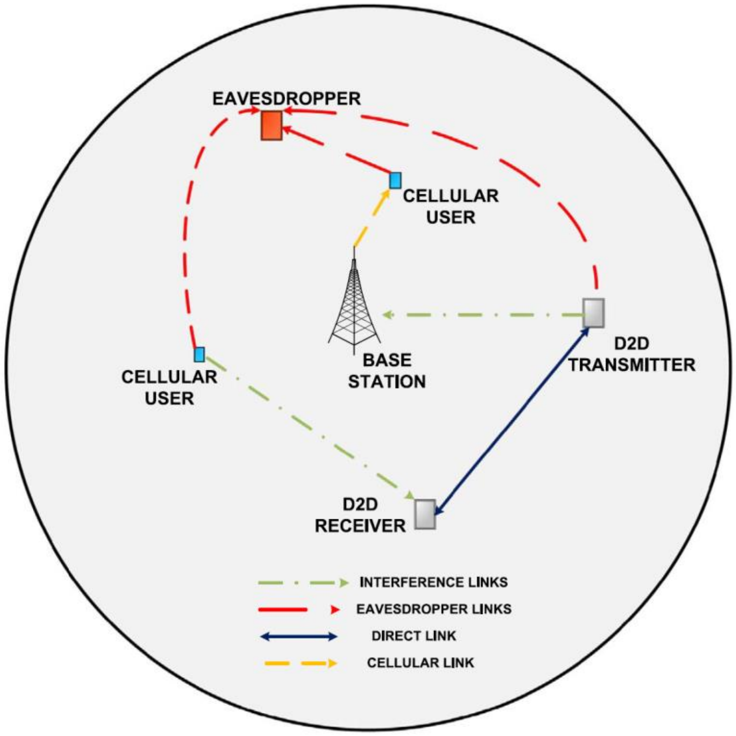

Figure 9-A D2D scenario, with eavesdropper [13]

6.1 Security threats

threat model is based on three dimensions:

Insider vs. Outsider: The inside attacker is an authenticated user in the network and can communicate with other members. The outside attacker is a non-authentic intruder with less privileges than the insider, which leads to less threats [14].

Active vs. Passive: An active attacker can directly modify the network or mobile device to obtain sensitive information. For instance, modifications include change, delete, create, delay or replay of messages. On the other hand, the passive attacker acts in the background and does not affect the mobile device or network. The adversary listens, collects, and analyzes data. Once the passive attacker has access to the system, it is hard to detect this adversary [14].

Local vs. Extended: The local attack is limited in scope and adversely influence only a few systems. An extended attacker can control multiple entities scattered across the network [14].

	Insider & Local	**Outsider & Extended**
	Target: Mobile Device	***Target: Wireless Connection***
Active	malware & ransomware, app rewriting, hijacking, information leakage, social engineering, masquerading	jamming, denial of service, session hijacking, impersonation, replay, delay, drop, repudiation, data corruption
Passive	location tracking, context monitoring	eavesdropping, man-in-themiddle, traffic analysis

Table 7-D2D threat model

6.2 SECURITY SOLUTIONS FOR D2D

D2D communication is vulnerable to diverse attacks due to the broadcast nature of wireless communication [14]. security solutions can be categorized into five domains [14]: (1) key management, (2) authentication, (3) confidentiality and integrity, (4) availability and dependability, and (5) secure routing and transmission, as Fig.10.

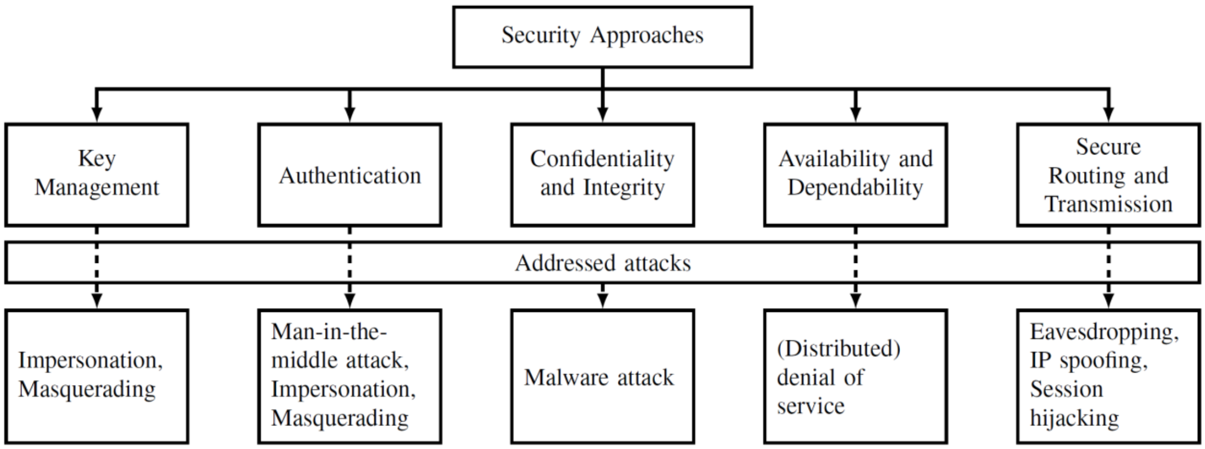

Figure 10- Classification of security approaches in D2D communication and addressed attacks [14]

A. Key Management

Key management is a basic procedure for security to generate, store, exchange and update keys D2D communication in LTE-Advanced [14]. Solutions and approaches which reviewed in [14] could be summarized as below:

- Key agreement and batch authentication for peer-to-peer (P2P) based online social networks (OSNs)
- Attribute Based Encryption (ABE) for secure data exchange in delay tolerant networks (DTNs)
- Group key agreement (AGKA) protocol based on Elliptic Curve Cryptography (ECC)
- In M2M networks, most approaches use Group Key Agreement (GKA) and Group Key Management (GKM). Each M2M device shares a group key with other devices in the same group [14]
- Dynamic updating policy for GKA in M2M LTE-A networks.
- Group based access authentication by aggregation signature
- Securely find localized content in the network. Searchable encryption (SE) creates an encrypted search index generated over a data collection to protect the content without appropriate tokens [14].

B. Authentication

Authentication is a key factor for secure D2D communications to resist a multitude of attacks. It must be ensured that only authenticated devices can use the D2D service. There are two types of authentication: entity authentication and data authentication [14]. Methods mentioned in [14] for reviewed papers are:

- Key agreement and key management to provide authentication in D2D communications.

- Authentication based Diffie-Hellman key agreement and commitment schemes.
- Public Key Cryptography (PKC), based on digital signature, and mutual authentication provide user authentication, non-repudiation, traceability, and integrity.
- Secure Data Sharing (SeDS) protocol for D2D communication: based on Diffle-Hellman Key Exchange (DHKE) and HMAC digital signature to provide authentication and malicious node detection.
- Secret key generation (SKG): combines user generated randomness and channel randomness to create a shared secret key under active attacks.
- Secret key generation scheme with multiple untrusted relays.

C. Confidentiality and Integrity

Confidentiality and integrity are important for D2D communication to secure the user contents and enable legitimate users to decrypt content [14].

- key extraction protocol based on Channel State Information (CSI) to avoid leakage of key information.
- KEEP: uses a validation mechanism to obtain secret keys from CSI measurements of all users.
- Power allocation technique for the generation of secret keys in relay-based LTE-A networks.
- Cooperative key generation to set up shared secret keys between devices.
- LBS-AOMDV is based on multipath coded information transmissions, data splitting, and data shuffling schemes. preventing eavesdroppers from obtaining information from legal users [14].
- Privacy preserving mutual authentication scheme: Scheme first identifies social relationship based on similar user attributes. Then, the D2D users are able to share their encrypted content and only users with similar attributes can decrypt the content [14].

D. Availability and Dependability

Availability guarantees that the authorized user is able to access the D2D communication. Denial of service is referred to as non-availability of service that should be available [14].

- Wireless Power Transfer Policy (WPTP) and an information signal model to enable wireless energy harvesting and secure information transmission.
- Power transfer model (policies): Cooperative Power Beacons Power Transfer (CPB-PT), Best Power Beacon Power Transfer (BPB-PT) and Nearest Power Beacon Power Transfer (NPB-PT).
- Identity Based Encryption (IBE) to secure the exchanged D2D messages during discovery and communication. Elliptic Curve Digital Signature Algorithm (ECDSA) provides non repudiation.

E. Secure Routing and Transmission

The information exchange between D2D users must be secured. Methods used to overcome problems and mentioned in [14] are:

- Physical layer security in multi-tier heterogeneous cellular networks (HCNs) using an average received signal power (ARSP) policy in which the users can only create a connection with the base station providing highest ARSP value [14].

- Optimization problems: robust power minimization and robust secrecy rate maximization. approximation solution based on Bernstein-type inequality and S-procedure to solve these optimization problems [14].
- Interference avoidance scheme for cooperative D2D communication in cellular systems using two approaches: first approach is a CSI-free criterion, which aims at system SEP optimization and low complexity. The second approach is a CSI-based criterion for security and reliability with high complexity [14].
- Secure Message Delivery (SMD) protocol to securely transmit data from source to destination.

Secure transmission protocols for ad hoc networks:

- Inspired Biotic Hybrid Cryptography (IBHC) to protect ad hoc wireless networks against heterogeneous attacks.
- SRPAHA protocol which enables cryptographically secure communication among nodes using Hybrid DNA-based Cryptography (HDC).
- Dynamic trust management for secure routing optimization with two social trust metrics: healthiness and unselfishness to deal with malicious and misbehaving nodes outperforming Bayesian trust-based routing and PROPHET.
- Trust based epidemic routing (TBER) addressing the selfish problem.
- Combined faith value (CFV) to reduce the harmful effects of malicious nodes in the network.

6.3 PRIVACY SOLUTIONS FOR D2D

Proximity-aware applications based on D2D and mobile social networks are facing various privacy challenges, such as location privacy, identity privacy, trust and malicious attacks [14]. Privacy as a key concern in D2D communication to prevent leakage in illegal usage of sensitive data. Privacy could categorize in four domains [14]: *Access Control, Obfuscation, Anonymity, Cryptography*.

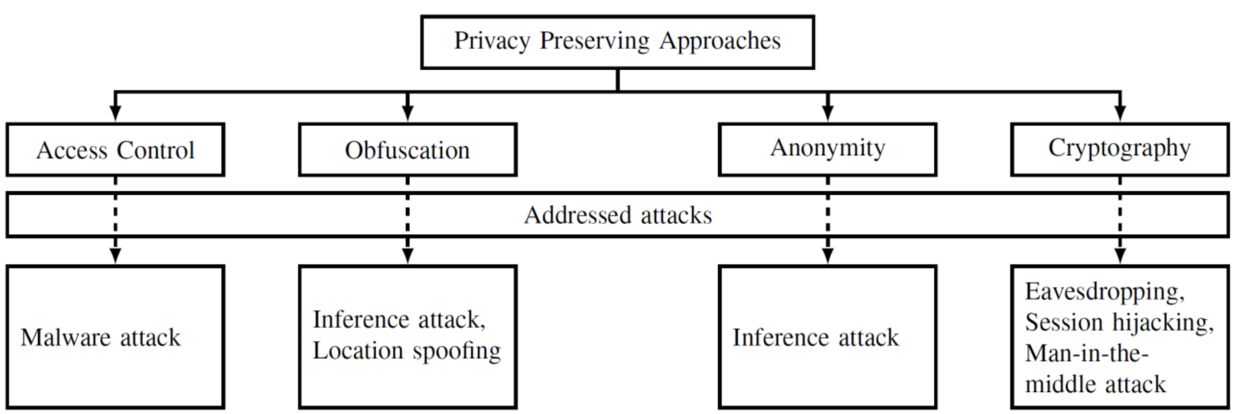

Figure 11-Classification of privacy preserving approaches and addressed attacks [14].

A. Access Control

The idea of access control is to grant or deny a given service provider or other users the right to perform a given action on user's private information. The user should decide whether to share this information or not during the D2D communication. Therefore, the mobile user needs additional mechanisms to control information flow [14].

Three different context-aware access control techniques [14]:

- authorization with Discretionary Access Control (DAC) depends on the identity of the subject and is well suited in unstructured domains like generic Internet services.
- Role-Based Access Control (RBAC) takes advantage of the subject role within a structured organization, such as a company or hospital.
- Mandatory Access Control (MAC) uses a sensitivity level assigned to each object and a policy defines which sensitivity level is allowed to access the private information.

Most systems for access control use semantic web technologies, such as OWL ontologies, RDF or SWRL to model privacy policies, user context or roles [14].

B. Obfuscation

The goal of obfuscation is to degrade the quality of information and protect the user identity. Usually, obfuscation methods are based on generalizing the information or by providing fake information to achieve the aforementioned goal [14].

C. Anonymity

Obfuscation hides the user identity by reducing the data accuracy. This may result in a negative impact on the service quality. Anonymity-based techniques overcome this problem by protecting the user identity without sacrificing the information accuracy [14]. In the D2D domain, we need to couple the anonymization technique with a reputation mechanism to create trust among the anonymous conversation entities [14]. Methods used in reviewed papers in [14] summarized below:

- Cryptographic blind signatures to anonymously verifing the reputation score of users.
- PEACE: splits all critical information like user identity and group secret keys into two parts and distributes them across different entities, such as group manager and network provider.
- Pseudonyms: an identifier of a subject other than one of the subject’s real names

Additional techniques to exchange pseudonyms between mobile users for non-linkability:

  - *Periodical change*: randomize the period to change pseudonyms
  - *Context-based mix zone*: detect and create a dynamic mix zone in social spots such as crowded environments
  - *Collaboration*: nearby users communicate with each other to synchronize their pseudonyms to confuse the adversary

D. Cryptography

Cryptographic approaches achieve several privacy goals, such as anonymity, unlinkability, content privacy, confidentiality, and integrity when exchanging messages between mobile users [14]. Standard and approaches used in D2D communication cryptography and reviewed in [14] are:

- Public Key Infrastructure (PKI) in which each participant has private and public keys to authenticate messages.
- Key management and distribution are a major problem for heterogeneous environments like D2D
- Multi-party and distributed cryptographic protocols:

- Identity-based Cryptography (IBC) requires a centralized trusted authority
- Signature schemes, such as group signature, provide anonymity and unlinkability for mobile users
- Homomorphic encryption (HE) especially when requesting data from untrusted entities (Paillier, ElGamal)
- Private Information Retrieval (PIR) to protect content in D2D communication
- Searchable Encryption (SE)

Conclusion

The aim of this article is to introduce D2D communication by focusing on Underlay D2D and to briefly describe it from different aspects. Most literature in D2D communication are focusing on Underlay D2D because of it's characteristics as mentioned in this article. There are lots of new ideas and technologies based on 5G and D2D that will bring new services and applications for all kind of users, individuals or corporate wise. Focus of this article is to give a brief review about recent achievements by investigating comprehensive surveys in underlay D2D communication as a promising technology that affects different aspects of human life.

[1] N. A. a. M. O. Magri Hicham1, "DEVICE-TO-DEVICE (D2D) COMMUNICATION UNDER LTE-ADVANCED NETWORKS," *International Journal of Wireless & Mobile Networks (IJWMN),* vol. 8, no. 1, 2016.

[2] D. K. S. Udit Narayana Kar, "An overview of device-to-device communication in cellular networks," *https://doi.org/10.1016/j.icte.2017.08.002,* 2017.

[3] J. R. E. Shahid Mumtaz, Smart Device to Smart Device Communication, Springer, 2014.

[4] R. N. Y. Z. Omar Hayat, "In-Band Device to Device (D2D) Communication and Device Discovery: A Survey," *Springer,* no. Springer Science+Business Media, LLC, part of Springer Nature 2019, 2019.

[5] J. G. A. A. G. a. R. R. Xingqin Lin, "An Overview of 3GPP Device-to-Device Proximity Services," *IEEE,* 2014.

[6] Y.-D. L. a. Y.-C. Hsu, "Multihop cellular: A new architecture for wireless communications," *in Proceedings of IEEE Infocom,* vol. 3, pp. PP. 173-1282, March 2000.

[7] C. Q. S. D. a. O. T. H. Wu, "Integrated cellular and ad hoc relaying systems: iCAR," *IEEE Journal on Selected Areas in,* vol. 19, no. 10, pp. PP. 2105-2115, October 2001.

[8] J. G. A. a. A. G. Xingqin Lin, "Spectrum Sharing for Device-to-Device Communication in Cellular Networks," *IEEE Globecom ,* 2013.

[9] H. T. Li Wang, Device-to-Device Communications in Cellular Networks, Springer, 2016.

[10] Q. W. V. M. Arash Asadi, "A Survey on Device-to-Device Communication in Cellular Networks," *IEEE,* 2014.

[11] H. L. K. M. S. H. J. R. a. A. R. S. Mumtaz, "Smart direct-LTE communication: An energy saving perspective," *Ad Hoc Networks,* vol. 13, pp. pp. 269-311, Feb 2014.

[12] M. U.-R. M. M. M. A. I. a. R. T. Ghazanfar Ali Safdar, "Interference Mitigation in D2D Communication Underlaying LTE-A Network," *IEE,* 2016.

[13] R. K. J. S. J. Pimmy Gandotraa, "A survey on device-to-device (D2D) communication: Architecture and security issues," *Elsevier Journal of Network and Computer Applications ,* vol. 78, pp. PP. 9-29, 2017.

[14] M. W. A. Y. D. Y. L. S. T. a. J. O. Michael Haus, "Security and Privacy in Device-to-Device (D2D) Communication: A Review," *IEEE COMMUNICATIONS SURVEYS & TUTORIALS,* December 2016.

[15] M. Z. B. a. T. V. Pavel Mach, "In-Band Device-to-Device Communication in OFDMA Cellular Networks: A Survey and Challenges," *IEEE COMMUNICATION SURVEYS & TUTORIALS,* vol. 17, no. 4, FOURTH QUARTER 2015.