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CAPACITY ENHANCEMENT IN D2D 5G EMERGING NETWORKS: A SURVEY

Anthony Ejeh Itodo[1], Theo G. Swart[2]
Center for Telecommunications, Department of Electrical and Electronic Engineering Science, University of Johannesburg, South Africa[12]
anthony.itodo@kiu.ac.ug

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Corresponding Author

ABSTRACT
Several efforts are being made to improve the capacity of 5G networks using emerging technologies of interest. One of the indispensable technologies to fulfill the need is device-to-device (D2D) communication with its untapped associated benefits. Interference is introduced at the base station due to massive traffic congestion. The purpose of this research is to expand the knowledge of interference mitigation in D2D using stochastic geometrical tools which will result in capacity enhancement. This study uses a literature review method based on 5G and other already existing literature on D2D communication. More than one hundred and twenty papers on D2D communications in cellular networks exist but no precise survey paper on interference management to enhance capacity using stochastic geometrical tools exists. The contribution of this survey to theory is that apart from already existing capacity enhancement methods, interference mitigation using stochastic geometrical tools is another technique that can also be used for capacity enhancement in D2D communications.
Keywords: *5G, D2D, interference management, capacity*

1. Introduction

It has been shown that in terms of mobility, over 70% of the world's population will have connectivity by 2023 (Cisco, 2020). Another important prediction is that over 10% of the global devices and connections will be 5G based by 2023 and the growth of mobile devices will scale from 8.8 billion in 2018 to 13.1 billion by 2023, out of which 1.4 billion of these devices will be 5G compliant. In terms of performance, 5G speeds are projected to be 13 times higher than the average mobile connection by 2023, and the estimated 5G speed is projected to reach 575 Mbps. Looking at the expected growth in mobile applications by 2023, about 300 billion mobile applications will be downloaded in 2023 globally and out of these, gaming, social media, and business applications will form the majority. These are depicted in Fig.

Cellular Generations

The fifth generation (5G) networks are an offshoot of the superfast fourth generation (4G) networks. Before the mentioned generation of mobile technology, the first generation (1G) networks came into the limelight in the 1980s built on an analog system with a data rate of about 2.4 kbps. This generation's mobile technology depended mainly on voice calls. In terms of security, it was not reliable since calls are stored and played at the base station. Next in line was the second generation (2G) networks which were introduced sometime in the 1990s. 2G is an improvement over 1G in terms of speed.

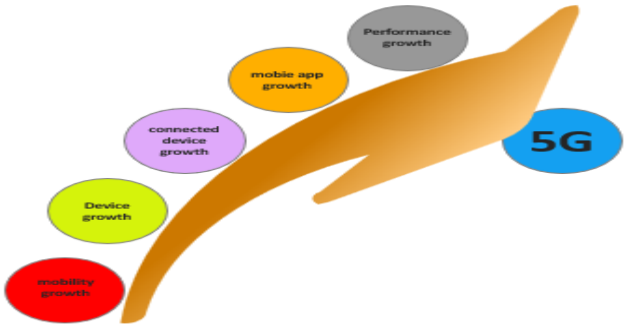

Fig. 1. Growth in mobility, devices, connected devices, mobile applications, and performance

It employs the use of digital technology with an improved data rate of 64 kbps when compared to 1G. 2G was also mainly designed to handle voice calls, but with the capacity to also handle email services, short message services (SMS) and roaming services. Other notable technologies of interest built around 2G are the global system of mobile communication (GSM) and code division multiple access (CDMA). The third generation (3G) networks, with an improved data rate of 2 Mbps, were introduced in late 2000. This generation of mobile technology is built on the internet protocol (IP).

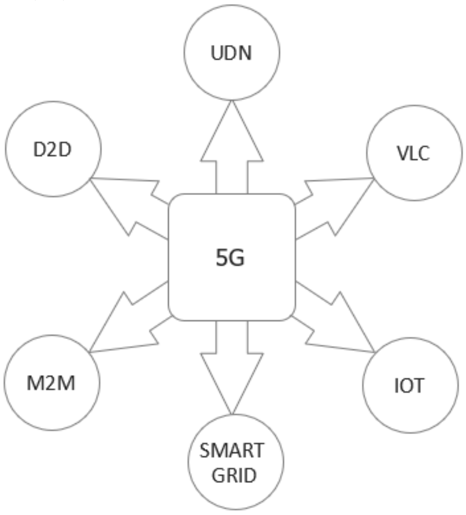

Fig. 1. Typical 5G architecture

Although 4G was designed to be a superfast technology, it was meant to handle services before the advent of the large usage of smartphones and the internet of things (IoT). Considering the prediction in (Cisco, 2020), 4G will no longer be enough to handle such exponential growth in traffic in the coming years, since many data-hungry devices are on the increase globally. That is to say that one major need for any 5G implementation is to be able to handle the global rise in the numbers of users with 5G-enabled devices with an improved data rate. 5G was designed to achieve higher spectral efficiency compared to that achieved with 4G. Several emerging technologies have been proposed to enhance the increase of spectral efficiency in 5G, namely device-to-device (D2D) communication, visible light communication (VLC), and ultra-dense networks (UDNs), just to mention a few (Salah et al., 2021)(G. Liu & Jiang, 2016). **Error! Reference source not found.** depicts the 5G system architecture. In this survey, we shall be considering D2D communication networks only. A typical 5G architecture comprise of several technologies that will drive 5G networks like D2D, VCL, machine-to-machine (M2M), Internet of Things (IoT), Smart, grid etc. as shown in Figure 2

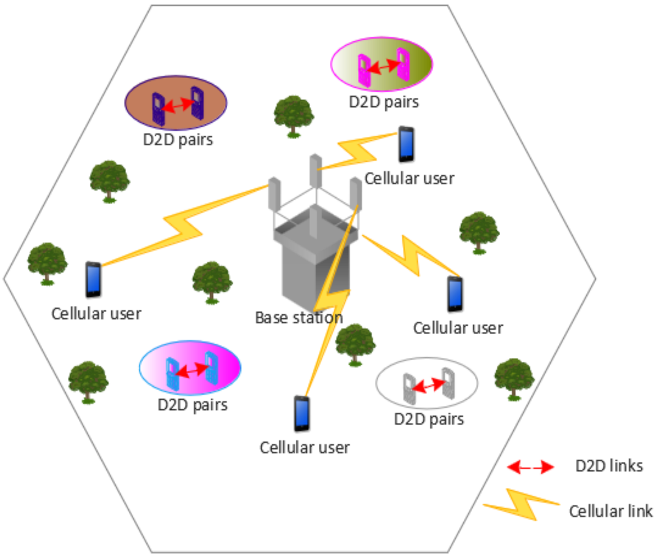

Fig. 2. Typical D2D network

D2D network communication involves direct communication between two mobile users by bypassing the base station. This direct communication contributes to low delay, relatively higher bit rates, and possible low power consumption due to the proximity of the communication. Fig. 2 depicts a typical D2D network showing D2D-link pairs and cellular user links. A typical D2D network comprises of D2D pairs, cellular users, and a base station. In such a system, a D2D can communicate with its pairs by bypassing the base station as shown in Figure 3. The traditional cellular network involves communication that exist between a cellular device and the base station.

With the exponential increase in the connected devices today which leads to huge traffic volumes, there is need to combine current solutions to limitations with the aim of improving 5G communication architecture to support more users or in other words enhancing capacity (Shariat et al., 2019). This huge traffic congestion normally will increase the interference level in the network. Efforts made to improve the performance of cellular systems were initiated by the Third Generation Partnership Project (3GPP) by providing Enhanced-Long Term Evolution (LTE) radio interface often referred to as LTE-Advanced (LTE-A). LTE-Advanced comprise of technologies like massive Multiple-Input-Multiple-Output (MIMO), D2D communication (Dar et al., 2016). D2D therefore, is a promising technology that will aid high performance in 5G in terms of capacity enhancements (Garlapati & Jayakumar, 2018).

To be able to mitigate the issues of interference, several researchers in both academia and industry came up with several proposals, namely graph theory, game theory, non-orthogonal multiple access (NOMA), and machine learning (ML) approaches (Budhiraja et al., 2019). By efficiently allocating radio resources like channels, power, and spectrum, interference can also be brought to a minimal level.

Contribution

The existing surveys on D2D communication (Asadi et al., 2014) (J. Liu et al., 2015) (Gandotra & Jha, 2016) (Pedhadiya et al., 2019) (Gismalla et al., 2022) (Ansari et al., 2018) (Ahmed et al., 2018) (Nitti et al., 2019) (Waqas et al., 2020) (Malik et al., 2020) (Nadeem et al., 2021) (Jayakumar & S, 2021) (Borralho et al., 2021) (Shah et al., 2018) (Shamganth & Sibley, 2017) (Yazdani & MirJalili, 2017) (Ali & Ahmad, 2017)(Mach et al., 2015) (Jameel et al., 2018) (Noura & Nordin, 2016) thoroughly addressed various aspects of D2D and interference management for D2D communication specific issues. In this study, we focus on a capacity enhancement strategy with stochastic geometrical tools which is not handled in existing surveys. Table 1 depicts the major difference between our survey and existing ones. This survey will assist researchers in acquiring a detailed understanding of current D2D research directions that enhances capacity in 5G networks.

Table 1 - Comparison between this paper and other existing surveys

Reference	Stochastic Geometry Modelling	Interference Management	Generation	Resource Allocation	Mode Selection
(Asadi et al., 2014)	×	×	LTE	×	×
(J. Liu et al., 2015)	×	Yes	LTE-A	Yes	×
(Gandotra & Jha, 2016)	×	Yes	×	×	×
(Pedhadiya et al., 2019)	×	×	5G	Yes	×
(Gismalla et al., 2022)	×	Yes	5G, B5G & 6G	Yes	Yes
(Ansari et al., 2018)	×	Yes	5G	×	×
(Ahmed et al., 2018)	×	×	5G	×	×
(Nitti et al., 2019)	×	×	×	Yes	Yes
(Waqas et al., 2020)	×	×	×	×	×
(Malik et al., 2020)	Yes	Yes	LTE-A	Yes	Yes

(Nadeem et al., 2021)	×	Yes	5G	×	Yes
(Jayakumar & S, 2021)	×	×	5G & B5G	Yes	×
(Borralho et al., 2021)	×	Yes	×	×	×
(Shah et al., 2018)	×	×	LTE	Yes	Yes
(Shamganth & Sibley, 2017)	×	×	5G	×	×
(Yazdani & MirJalili, 2017)	×	×	×	Yes	×
(Ali & Ahmad, 2017)	×	Yes	5G	Yes	Yes
(Mach et al., 2015)	×	Yes	LTE	Yes	Yes
(Jameel et al., 2018)	×	Yes	×	Yes	Yes
(Noura & Nordin, 2016)	×	Yes	5G	×	Yes
This survey	Yes	Yes	5G	Yes	Yes

The remaining part of this survey is structured as follows. In Section 2, literature review was considered, Section 3 highlighted the research methodology employed in this work. Results and discussions were looked at in Section 4. The survey is ended with conclusion and future work in Section 5.

2. Literature Review

The benefits of the numerous advantages embedded in the introduction of D2D as an emerging technology in the deployment of 5G network is short-lived due to interference existing in D2D communication links. Over time several researchers have proposed methods to mitigate interference such as resource allocation, mode selection, power control and most recently artificial intelligence (AI). Researchers in (Yu et al., 2009) used a power control approach that controls the D2D transmission with the bid to protect the links that are involved from interference. Taking the same path of power control, researchers in (ElSawy et al., 2014), D2D underlaying power control and mode selection was researched. The joining of channel selection and power allocation scheme for D2D communication in (Kim & Dong, 2014) yielded a suboptimal performance. Further interference management efforts in D2D led researchers in (Gu et al., 2011) to propose a scheme based on power control for performance enhancements. Researchers in (D. Wang & Wang, 2014) worked on a dynamic power control scheme that determines an upper bound of the D2D transmitter using the coverage and base station location as a basis for the analysis. Further research around mode selection, resource allocation with the goal of enhancing QoS and at the same time minimizing consumption of power was investigated in (Xiao et al., 2011).

To reduce the interference that exist on cellular links, researchers in (Kaufman et al., 2013) adopted a distributed spectrum sharing scheme. The order of decoding signals and interference scheme was adopted to manage interference in (Min et al., 2011). By adjusting the transmission power of D2D user equipment, performance of cellular user equipment can be enhanced using an efficient resource allocation scheme (Gu et al., 2015). Further efforts to mitigate interference in D2D, made researchers in (Ma, Wu & Cui, 2015) to propose successive interference cancellation approach. In addition to their proposal, the performance of both D2D and cellular link were analyzed using stochastic geometrical tools.

The focus of this survey work is on the use of stochastic geometrical tools for the enhancement of D2D capacity in an interference prone system which was not considered by previous research works and survey-based works in detail. The survey focus will be stressed further as we consider the methodology of this piece of survey regarding capacity enhancement in D2D 5G based networks.

3. Research Methods

This study employs the literature review method. The source of our data is from the results of credible, scholarly research outcomes that are already published in online journals of international reputation.

We used the standard research procedures of looking for journals via accredited search engines like Google Scholar, Research Gate and IEEE Xplore, with key words like Device-to Device, 5G, interference mitigation, stochastic geometry, etc. and later did a filtering out to enable us to use the most appropriate and related published journals. Published scholarly journals between 2009-2022 form the basis of our data sources in this survey.

This section comprises of research questions, D2D classification and key issues, D2D communication challenges and mathematical modeling approaches to interference mitigation in D2D networks.

Research questions

The research questions that this survey attempts to answer that will guide this research study will be considered in this subsection namely:

- ✓ What are D2D classification and key associated issues as an emerging 5G technology?
- ✓ What are the challenges in D2D 5G emerging network?
- ✓ What mathematical modeling approaches can be used to mitigate interference in D2D 5G network?
- ✓ How to enhance capacity in D2D 5G emerging network?

D2D classification and key issues

This subsection looks at the overview of D2D communication classification using the occupied spectrum as a basis of classification. The broad categories are called inband and outband D2D. Next, we subdivide the inband into underlay and overlay, and outband into controlled and autonomous, respectively. This is depicted in Fig. 3. Table lists some properties of the inband an outband D2D.

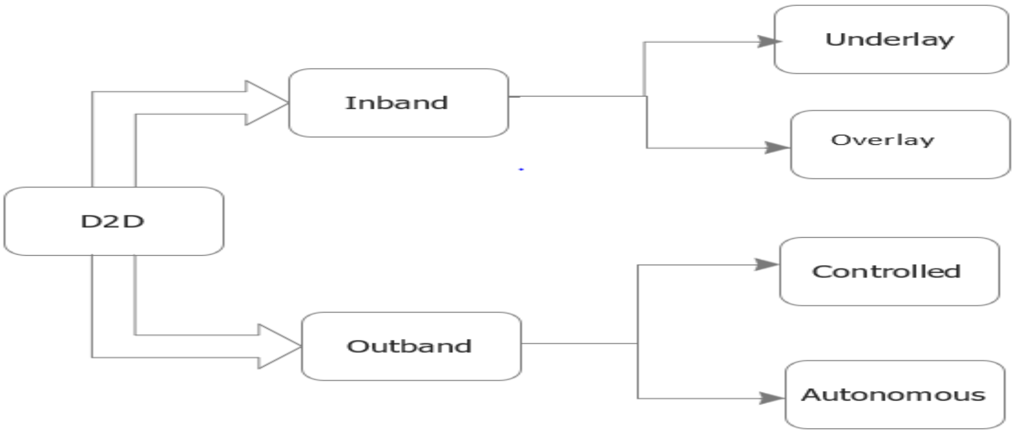

Fig. 3. D2D classification

Inband D2D Communication

Inband D2D communication is generally considered a choice approach in most research work because it supports high control for the cellular spectrum which is also referred to as the licensed spectrum. Inband D2D communication consists of spectrum sharing between cellular and D2D users. Inband D2D is further subdivided into the underlay and overlay D2D communication based on licensed spectrum dedication. D2D communication is said to be inband underlay when the same radio resource is shared among the cellular and D2D users. Overlay inband D2D communication occurs when dedicated resources are assigned. It is obvious that in terms of interference avoidance, the overlay inband is preferred since dedicated resources are assigned, but that approach does not enhance spectrum efficiency at all. One notable disadvantage of inband underlay D2D is the issues of interference that exist between D2D users and cellular users. This interference challenge can be resolved by employing advanced resource allocation techniques. Various techniques to enhance performance in underlay D2D communication have been proposed in literature (Ansari et al., 2018)(Ahmed et al., 2018)(Nitti et al., 2019).

Outband D2D Communication

D2D links use unlicensed spectrum in outband D2D. The major purpose of outband D2D is to avoid the existence of interference from either the D2D link to cellular or the cellular link to D2D. One strong condition for the implementation of outbound D2D by a mobile device is that such a mobile device must be embedded with two wireless interfaces, such as those found in Wi-Fi for example. That means the key requirement for the use of unlicensed spectrum by the D2D link is the availability of some other wireless technologies like Wi-Fi, Bluetooth, or Zigbee.

The outbound D2D is further subdivided into controlled D2D and autonomous D2D modes. In the controlled D2D mode, both the reliability and efficiency of D2D communication and general system performance can be enhanced by using a cellular-based network system (Hicham et al., 2016). The autonomous D2D mode's motivation is to decrease the overhead of cellular network-based systems.

Table 2 - Inband and outband properties

D2D Category	Description	Advantages	Disadvantages
Inband D2D	The use of licensed spectrum for both D2D links and cellular links.	Capacity can be enhanced in underlay D2D.	Wastage of resources in overlay D2D.
Outband D2D	The use of unlicensed spectrum for D2D links.	Interference does not exist between D2D UEs (DUEs) and cellular UEs (CUEs).	Requires two wireless interfaces, hence more power consumption resulting in poor energy efficiency.

Key Issues Surrounding D2D Communications

In D2D communication, user equipment (UE) is in proximity to each other and hence the reduction in the transmit power needed for communication when compared to cellular communication transmission. One advantage of reduced transmit power is the longevity of battery life used in various mobile devices. As a result, the choice of D2D communication is the inband D2D. Outband is the other way D2D can be categorized. Under this categorization, which requires two wireless interfaces, more energy will be expended as compared to inband D2D which requires only a single interface, hence outband D2D tends to reduce energy efficiency. Once again, the motivation for outband is the absence of interference between D2D users and cellular users when compared to inband D2D since a dedicated spectrum is assigned. Therefore, interference management in inband D2D is the main research issue. But in terms of capacity enhancement, inband D2D can be appropriately researched by mitigating interference to improve system capacity, which is the motivation for this survey. The focus of this survey henceforth is on inband D2D and precisely on underlay D2D communication.

D2D Communication Challenges

In this subsection, we shall look at a few advantages brought by D2D and then consider a few design challenges associated with the implementation of D2D communication.

Device Discovery

The first thing that happens in D2D communication is the discovery of the neighbor device. Sometimes this is also called peer discovery. A D2D device can discover another device based on their proximity under some short time duration (Zhang et al., 2015) and also whether the neighbor device wishes to be discovered, as described in (R.Wang, 2016). This peer discovery is due to the device sending a request to the neighboring device with both the channel state information (CSI) and its distance details. Generally, we have two device discovery methods, namely centralized discovery and distributed discovery.

(i) *Centralized Discovery*: As the name implies, the two devices discover each other with the participation of a central device like the base station. The sending device notifies the base station of its intention to transfer data. The base station gathers information, like availability, location,

channel state quality, and interference power control quality, and then shares it between the participating devices. The level of involvement of the base station in the communication chain further divides the central discovery approach into full and partial.
(ii) *Distributed Discovery*: In this device discovery type, both discovery and connection establishment is done without the instrumentality of the base station. Here, messages like CSI and availability status, are transmitted between the two devices that are interested in D2D communication. Since the messages are not center controlled by the base station, the possibility of interference cannot be absent.

Mode Selection in D2D

When two devices communicate with each other via the base station, we generally refer to such communication as traditional wireless communication. D2D communication extends the available mode of communication to either cellular or D2D and sometimes the possibility of combining both D2D and cellular is referred to as hybrid mode (Doppler et al., 2010). The base station acts as a relay between the two devices communicating in the traditional wireless communication network. Categorizing this mode based on the spectrum used for communication, we can subdivide the D2D mode into reuse mode and dedicated mode (Hoang et al., 2017). A mode is said to be reuse D2D when the spectrum used by cellular communication is reused. It is sometimes called the underlay D2D mode. In this mode, data is transmitted directly while reusing the downlink (DL) and uplink (UL) resources of the cellular spectrum. Dedicated D2D mode is also referred to as the overlay D2D mode. As the name implies, a dedicated spectrum is assigned for communication. It is important to note that the mode of use for any communication depends on the distance between the devices involved in the communication, the channel gain, the quality of service (QoS), and the transmission power of the sending device.

Table 2 - Analytical methods

Reference	Analytical Technique
(Wei et al., 2014)	Poisson point process
(Peng et al., 2009)	Interference avoidance mechanism
(Ghazanfari et al., 2015)	Lagrangian algorithm
(Tanbourgi et al., 2014)	Poisson Veronoi tessellation
(Shah et al., 2015)	Proportional fair resource allocation
(Tehrani et al., 2014)	Game theory
(Ma et al., 2015)	Successive interference cancellation
(Hoang et al., 2014)	Resource and power allocation algorithm
(Gao et al., 2014)	Joint algorithm
(He et al., 2014)	Stackelberg game

Security Issues

Security in D2D communication is a major challenge since no central entity controls the security of the network (Haus et al., 2017; A. Z. and X. Lin, 2017). The main security challenge experienced in D2D communication is relay attacks, eavesdropping, masquerading, man-in-the-middle attacks, and malware attacks. D2D requires a more secure data transmission to be able to withstand possible threats. Currently, much research work is needed to secure D2D communication for it to enhance the goals of 5G networks which are seen to be heterogeneous. The introduction of authentication and a key agreement could increase the overall overhead of D2D communication and there is a need to consider some tradeoffs.

Interference Management

Interference in a cellular network is said to be increased whenever D2D communication is introduced. Interference management is a key challenge in D2D-based communication (Safdar et al., 2016). One major motivation for D2D is the offloading of data traffic at the base station and hence increasing the spectral efficiency by frequency reuse.

One of the main sources of interference is the sharing of the spectrum that exists between cellular and D2D communication. Interference generally is split broadly into co-tier and cross-tier. As the name implies, interference that exists between two D2D communication users is referred to as co-tier interference, while the interference that exists between a D2D communication user and a cellular user is referred to as cross-tier interference. Interference generally degrades system performance and QoS and as a result, will not allow D2D communication to meet the design requirements of a 5G network. One major reason for interference occurrence is poor resource allocation design and hence can be minimized or mitigated using advanced methods (Hassan et al., 2017).

Looking at the management of interference-based schemes, we can see that it is broken down into a centralized approach, distributed approach, and semi-distributed approach depending on the applied algorithm. These classifications can also be referred to as the interference control level.

An approach is said to be centralized when the base station fully manages or handles the interference that exists between D2D and cellular users. The base station must gather information, like the interference level (IL) of a given user, CSI, and quality of the channel (CQ). This gathered information will be used by the base station to determine the allocation of resources to D2D user equipment (DUE) and cellular user equipment (CUE). In a centralized approach, as user numbers increases, the overall signaling overheads tend to increase since the control is just from a single point. This interference approach is good for small-sized D2D networks.

By the same token, a distributed interference control approach does not entail a central control of the base station, but DUEs do the management themselves. In this approach, the overall overhead is reduced since CSI and expected huge feedback are also reduced. This interference control approach is most appropriate for large-sized D2D networks.

By considering the merits and demerits of both interference management control levels already discussed (centralized and distributed), a certain level of tradeoff can be drawn out which we can now refer to as a hybrid or semi-distributed interference management scheme. This interference management control level is most appropriate for a moderately large network.

Resource Management

Power control and interference management can both be referred to as resource management, since the two are the main resources that when properly handled will enhance performance in the network. This management can be handled centrally or distributively. As the name implies, centralized management entails the base station is responsible for the monitoring of the system performance, channel quality and signal-to-interference plus noise ratio (SINR), and call setup. The disadvantage of the centralized approach is that it can only support a small cell network. The distributed approach can handle larger networks, since it does not involve a base station and as a result, the devices handle the allocation and management of the available resources themselves. An efficient allocation of resources, like spectrum and power, will lead to a minimization of interference in the D2D communication network (Yu et al., 2011)

Mathematical Modeling Approach to Interference Mitigation in D2D Networks.

In this subsection, we shall discuss interference management schemes in D2D-enabled cellular networks which have over time been modeled and analyzed using mathematical theories, including game theory, graph theory, and stochastic geometry. The design of automated decisions under interference management is enhanced using these mathematical theories.

Game Theory

Game theory is a branch of applied mathematics that studies how rational players interact among themselves in a scarce network resource scenario to obtain a stable resource that will be enough to meet the service requirements for the players.

The modeling and analysis of complex interactions that exist between rational players interacting among themselves that lead to the player's choice of strategy can be handled using the game theory approach. This effort enables this mathematical tool to handle strategy development which tends to reduce interference in networking and wireless networks. Game theory was used in cognitive radio (W. Wang et al., 2016), sensor networks (Abdalzaher et al., 2016), and mobile social networks (Chen et al., 2015), (Farhat Anwar, Mosharrof H. Masud, Burhan ul Islam Khan, Rashidah F. Olanrewaju, 2018). It is one of the most used mathematical tools in interference management in research work. Game theory is generally used to resolve competitive problems and hence is a good interference management design and analysis tool. Game theoretical models used in solving D2D resource allocation are generally classified into two, namely cooperative and non-cooperative. Non-cooperative game theory models handle choices that result from the specific actions of the players in competition, while cooperative game theory models are used to study the behavior of the competing players. Cooperative games are generally preferred for the designing of fair, robust, practical and efficient cooperation strategies in communication networks (Moura & Hutchison, 2018).

Graph Theory

Another mathematical tool that can be used in handling interference management-related issues in D2D communication is known as graph theory. It can be used for the modeling and analysis of various types of interactions in different networks. When graph theory is used in interference management, CUEs and DUEs appear at the vertices of the graph while the edges of the graph represent the interference between the vertices. The weights of the edges can then be used to represent the extent of interference existing between the vertices. This mathematical tool is used when the interference relationship between D2D links and cellular links can be represented with a graph and then the resulting graph can be used to develop strategies to reduce cross-tier and co-tier interferences (Noura & Nordin, 2016). Researchers (Han et al., 2014; Tsolkas et al., 2012; R. Zhang et al., 2013) used graph theory to investigate interference management in D2D communication.

Research work in (Zhang et al., 2015) investigated resource-sharing problems to optimize the performance of D2D communication in an underlay scenario. The interference relationship that exists between D2D links and cellular links was formulated as an interference-aware graph with attributes defined. A resource-sharing algorithm was proposed to solve the interference-aware graph. It was observed that the interference aware graph-based resource sharing achieved a tradeoff between computational complexity and the performance of the network.

The work in (R.Wang, 2016) researched a graph coloring secondary resource allocation scheme for D2D transmission in LTE networks. Intra-cell communication requests were served by the spatial spectrum opportunities in the UL. A step taken to support this service, UEs require extra functionality to be able to inform eNB of possible interference conditions in its environment. The information, that now consists of the results of the resource allocation, can now be shown as a graph by utilizing a graph coloring algorithm that provides interference-free secondary resource allocation. The result of this research confirms that the intra-cell traffic can be served by spatial spectrum opportunities on the condition that data rate (gain) is offered to the inter-cell traffic.

Stochastic Geometry

Stochastic geometry is a rich branch of applied probability brought into the study of random phenomena of networks in mostly large-scale scenarios. Wireless networks can be modeled using stochastic geometry by looking at the whole network as a stationary random model in Euclidean space and considering the analysis from the probabilistic point of view. Another important part of stochastic geometry is that key performance characteristics, like capacity and coverage area, can be obtained by properly estimating spatial averages. Stochastic geometry can be used to define and compute properties of networks with topological randomness, as it is a powerful mathematical tool for modeling random patterns of points. It has been extensively used in modeling large-scale networks in (Jayakumar & S, 2021)(Borralho et al., 2021)(Shah et al., 2018)(Shamganth & Sibley, 2017)(Yazdani & MirJalili, 2017). It is important to know that one advantage of using stochastic geometry (Ali & Ahmad, 2017) in modeling is that its result is tractable and independent of network topology.

4. Results and Discussions Of Stochastic Geometry-Based Interference Management And Modeling Approach.

This section provides a quick response to the fourth question of the research; how to enhance capacity in D2D 5G emerging networks? Capacity can be enhanced by efficiently mitigating interference in D2D 5G emerging network. Interference is one of the serious problems in D2D communication networks. Due to the unexploited advantages embedded in D2D technology as an emerging technology to aid the deployment of 5G network and beyond, a thorough mitigation of interference using stochastic geometric tools is required. In this section, we shall survey past interference management approaches employed to mitigate D2D interference-associated issues using stochastic geometry under mode selection and power control.

Mode Selection Literature

The decision to select a cellular mode or D2D mode in a D2D underlaying network is challenging to handle. As the name implies, D2D mode implies the transmission of data packets over a direct link between user equipment hence reducing latency, while cellular mode entails communication that can occur if there exists proximity between two devices through the base station.

Efficient mode selection techniques can be employed to mitigate both cross-tier and co-tier interference in D2D communication. Various researchers concentrate on several key factors when attempting to mitigate interference in D2D communication. In (Xing & Hakola, 2010), the concept of different path loss was used as a means of analysis, while in (Doppler et al., 2010) the strength of the received signal was used as the analysis basis. In (ElSawy et al., 2014; Lin et al., 2014), the existence of physical distance between participating devices was used as the research ground for investigation.

In this review work, we wish to focus on works that enhances interference mitigation via mode selection techniques using stochastic geometrical tools, as opposed to previous works done. This will openly show how capacity can be enhanced by efficiently mitigating interference in D2D 5G based network and it will also show how a D2D communication stands out as an emerging technology in 5G and beyond networks the moment interference issues are efficiently solved.

Other mode selection strategies used were based on the quality of the channel (Janis, P., Yu, C.-H., Doppler, K., Ribeiro, C., Wijting, C., Hugl & Tirkkonen, O., & Koivunen, 2009; Yu et al., 2009). To be more precise, in (Xing & Hakola, 2010) the mode selection criteria used was the sum rate of the connection that exists between D2D and cellular user pairs.

In (Kamruzzaman et al., 2019), a stochastic geometry model was employed to select the appropriate mode for efficient transmission of D2D pairs. In this proposal, care was taken to accurately model the random position of the device location and users by using a Poisson point process (PPP).

In (Huang et al., 2018), mode selection for D2D was investigated from an energy-efficient perspective point. The success probability and ergodic capacity were analyzed for D2D and cellular links using stochastic geometry. The result of this work shows that an efficient mechanism is needed for D2D users to be able to select appropriate modes.

In (Hicham et al., 2016), the researchers proposed that selecting an appropriate mode from a pool of communication modes tends to enhance the energy efficiency of the system. In (Zhang et al., 2015), mode selection based on the degree of freedom was investigated, where interference is managed by employing a linear interference alignment approach. In (Ghazanfari et al., 2015), a scheme to manage interference was investigated by using stochastic geometry to investigate the outage probability for D2D receivers and associated spectrum reuse ratio issues. This analysis helps in managing interference by appropriately selecting the mode in the cellular network. In (Tanbourgi et al., 2014), the network capacity for cellular modes and D2D reuse was investigated using stochastic geometry. This was achieved by maximizing the network capacity and optimizing the mode selection threshold. In (Shah et al., 2015), the transmitting powers of cellular and D2D users and mode selection were investigated using stochastic geometry based on the maximization of the average rate of transmission.

Existing works have used stochastic geometry for other investigations but not much emphasis on capacity enhancements issues. There is need for more research investigations that thoroughly focus on interference mitigation using stochastic geometrical tools that will efficiently enhance the capacity of D2D as an emerging technology in 5G deployments.

Power Control Literature

In wireless communication, the transmit power provided is one of the factors that determines the service quality (Liu, M. et al., 2020). An increase in power will result in a wider area of coverage. Caution should be taken not to increase the power beyond a threshold since it can lead to transmitter or receiver interference (Nugraha et al., 2018). It is very important to manage interference in the communication system by properly controlling the output power in a cellular system. In general, power control strategies are employed to efficiently manage interference in wireless communication systems.

The work done in (Yu et al., 2009) uses a statistical approach to come up with a power control mechanism for D2D that ensures the SINR value is maintained below a given threshold for cellular users in a cross-mode interference scenario. However, the analysis is limited to a single D2D link, single cellular user, and single cell respectively.

A similar statistical approach was used in (Syu & Lee, 2013) to determine the maximum D2D intensity that can accommodate a cellular uplink network under an interference threshold level. These researchers also investigated four network models under which the exclusion region was used to reduce or mitigate the effect of interference from UE to the base station with the objective of enhancing the quality of service (QoS) of the network.

In (Liu, Z. et al., 2013), the optimal transmit power and intensity that achieves the maximum achievable transmission capacity for a D2D-enabled network was investigated under an outage probability constraint. D2D links utilized disjoint bands. The theoretical result from this research shows that the interference from the primary section on both bands can be used to determine the optimal density of D2D and that power allocation ratio is greatly dependant on the transmission power of the primary system.

In (ElSawy et al., 2014), a model that statistically characterizes D2D communication was proposed. A combination of a flexible mode selection scheme and truncated channel inversion power control was developed. The result of this work shows that the underlay D2D can improve spatial frequency reuse, link, and spectrum efficiency.

In (Guo et al., 2014), interference management in D2D communication was investigated at the cell edge. The main motivation for this work was the enhancement of capacity via interference management of the system. The interference strategy used was the interference suppression area (ISA) algorithm. An increase in capacity was achieved when the ISA algorithm was employed as compared to when the ISA algorithm was not used.

By reviewing many recent research works in relation to D2D capacity enhancement via interference mitigation, we observed that these works are scattered ranging from specific D2D issues to D2D application and design. Most of the research within this context used channel selection, power control, mode selection, resource allocation, successive interference cancellation, and sometimes the combination of these outlined approaches to mitigate interference. The emphasis was not on the use of stochastic geometrical tools to enhance the capacity of D2D by mitigating interference in 5G network scenarios.

To effectively mitigate interference in underlaying D2D, an effective power control approach using stochastic geometrical tools is needed. This approach will enhance the capacity of the D2D communication and hence assist in easy 5G deployments.

5. Conclusion

D2D communication stands to be one of the key emerging technologies to catapult 5G networks into achieving one of its design goals, which is capacity enhancement. In this survey paper, we have considered existing D2D technologies by discussing their associated characteristics, like mode selection, resource management, and device discovery with a capacity enhancement motive in a 5G network by mitigating interference using stochastic geometrical tools. The limitation of this survey work is that we have not considered capacity enhancement in D2D using an artificial intelligence approach since that was outside the scope of this study.

Possible future works in this direction will be the need to accurately model D2D networks using stochastic geometrical tools with the focus of decreasing the overall interference contribution and hence a step to enhance capacity in D2D-based 5G network and beyond.

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