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Predicted characteristics of 5g version of mobile communication and self-interference cancellation in full duplex radio

Abstract

Fifth generation of cellular networks is coming in the next few years and we think that it will not be predicted as a development version of the existing one. The wireless research community aspires to visualize full duplex operation by supporting concurrent transmission and reception in a single time/frequency channel for the sake of improving the attainable spectral efficiency by a factor of two as compared to the family of conventional half duplex wireless systems. The main challenge encountered in implementing full duplex wireless devices is that of finding techniques for mitigating the performance degradation caused by self-interference. Self-interference suppression will represent one of the main merits that offered by the 5G Networks. In the existing version of mobile networks, the available spectrum is not sufficiently used whilst in the predicted version the spectrum will be employed in a more efficient manner in such a way that it will be approximately full all the operating time. The object of this paper is to scan the existing techniques that are concerned with self-interference cancellation on the level of antenna and system design to allow us to suggest some solutions for that problem in the incoming version.

Keywords: self-interference cancellation, fifth generation, frequency division duplex, time division duplex, antenna and system designs, passive suppression, radio access techniques

Volume 1 Issue 1 - 2017

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Received: June 25, 2017 | **Published:** July 20, 2017

Abbreviations: LTE, long term evolution; CEPT, conference for european post and telecommunications; GSM, global system of mobile communication; NG, next generation; QoS, quality of service; IOT, internet of things; M2M, machine to machine; IP, internet protocol; RATs, radio access techniques; MS, mobile station; CCI, co-channel interference; ACI, adjacent channel interference; MAI, multiple access interference; ISI, inter symbol interference; SI, self-interference; CEI, coexistence interference; MIMO, multiple inputs multiple output; FD, full duplex; HD, half duplex; D2D, device to device; BS, base station; DC-DC, d2d communication with device controlled link establishment; DC-OC, direct d2d communication with operator controlled link establishment; DR-DC, device relaying with device controlled link establishment; DR-OC, device relaying with operator controlled link establishment; FDD, different frequency bands

Introduction

Global system of mobile communication has many developments starting from 1980 (1G) passing by many modifications till 2010 that resulted in 4G. These versions introduce many services including voice, text, and multi-media. 3G and long term evolution (LTE) have the characteristics of transmitting and receiving data with high rate. However, there is an increasing demand on that rate to become higher and higher to reply that requirement. So, we are going forward towards next generation (5G) which will integrate all different technologies in such a way that the global service will be enhanced. These services include higher mobile data volume per area, huge number of connected devices, and longer battery life for low power devices, five times reduction in end to end latency and user data rate which will be higher 10 to100 times than the existing one. Fifth generation till now has no unique definition[1] and it is expected to be in use in 2020. Table 1 explores the summary and shows a clear image about the evolution which already achieved in the existing technology along with the predicted features for the next generation. Normally, it is well-known that the data can be transmitted and received on two separate channels; one channel is uplink and the other is downlink to achieve the performance requirements (Key performance indicator). This means that the system must operate at half duplex mode where transmission and reception cannot be achieved on the same frequency band. In this situation, self-interference will appear and it can destroy everything in the communication system. To overcome this problem, it is evident to search some means to realize and implement full duplex mode in order to transmit and receive on the same channel, or frequency band.[2–5] Therefore, it is of importance to try to eliminate this unwanted phenomenon, self-interference, in order to attain the goal of single channel. So, some techniques must be searched to remedy this problem or at least achieve its lowest value in such a way that its level shouldn't be larger than the desired signal. This minimization approach must be implemented in the stage of antenna system, RF part, and/or analog and digital signal processing. The technique of reducing self-interference takes two forms: the first one is related to electromagnetic isolation which is termed as passive suppression, whilst the second one concern with active cancellation.[6] The rest of the paper is organized as follows. Section II is concerned with the introduction of 5G generation vision and technology overview. Section III will explain and clarify the available techniques that support in reducing the amount of self-interference which is generated as a result of using any full duplex algorithm in communication system. Finally, our concluded remarks are outlined in section IV.

Table 1 Summary of mobile technology evolution

Version of generation	1G	2G	3G	4G	5G
Integration year	1970-1980	1990-2000	2001-2010	2011-2019	2020-
Technology	Analog Technology	Digital narrow band circuit data, packet data	Digital broadband,CDMA2000	Digital broadband,WiMAX, LTE	Predicted combination of broadband, LAN,WAN, WLAN
Service	Only Analog voice service	Digital voice service and packet, SMS, MMS	Audio, video streaming, video conference, web browsing	Optimized Audio, video streaming, video conference, web browsing, HD mobile TV	Predicted Dynamic information access, higher data rates, higher speed, offer new device to device, machine to machine communication, smart homes, IOT
Multiplexing Techniques	FDMA	TDMA	CDMA	CDMA, OFDMA	Predicted Any division duplex
Standards	MTS,AMTS, IMTS	GSM: 2G	IMT: 2000	A unified Standard LTE, WiMAX	
		GPRS: 2.5G	HSDPA: 3.5G		Single unified standard
		EDGE: 2.75G	HSUPA: 3.75G		
Core Network	PSTN	PSTN	Packet N/W	Internet	Internet
Operating Frequency	800MHz	GSM: 900MHz	2.1GHz	1.8GMHz	2.45GHz(Wi-Fi), 28GHz
		DCS: 1.8GHz			
Web standard	NA	WWW	WWW(IPV4)	WWW(IPV4)	WWW(IPV6)
Merits	Less complex network	Multimedia features(SMS, MMS)	High security, international roaming	High data rate, low latency compared to 3G, MIMO technology	Predicted to offer high speed, higher data rates, also D2D, M2M, and IOT
Demerits	Limited capacity, interference exist	Slow data rates	High power consumption, high cost of spectrum	Deployment is hard, more complex	More complicated to interconnection and implementation

Fifth generation technology

Through this section, we present the most important characteristics of the fifth generation of mobile communication technology such as vision, offered services and different types of connectivity. Owing to the role that these features may play in the technology of the mobile communication, we are going to discuss some aspects associated with these topics.

Vision and requirements

Global system of mobile communication was firstly started when the conference for European post and telecommunications (CEPT) administration formed a committee known as group special mobile. In 1990, the design development of global system of mobile communication (GSM) was summarized in a set of standards known as the "GSM specifications". The functionalities regarding evolved technologies were commenced from 1G which is defined as a basic mobile telephony services, then 2G which offers telephone service for massive subscribers. In addition to 2.5G which is considered as the base of mobile internet services, the third generation was emerged as an enhanced version of the internet services in mobile world. Finally, 4G or LTE was appeared. Moreover, LTE provides enhanced user experience for broadband wireless networks and supports scalable bandwidth from 1.25MHz to 20MHz. Furthermore, it has 100Mbps as downlink peak rate and 50Mbps peak rate for uplink along with enhancing the latency to be less than 100ms in control plane whilst its value is lower than 5ms for user plane.[7] Through the sequence of editions displayed in Figure 1, the fifth generation vision can be defined as means of what addresses and classifications of telecommunication will the market need in future or at least in next five years. In the predicted version, it is needed to increase the connections from Mega to Giga range, along with increasing traffic volume in conjunction with Figure 2. Additionally, the speed of transmission is predicted to be 10Gbps for data rate while the latency will be decreased to become 1ms. These are the necessary modifications for the nested strategy. Moreover, the power consumption is indispensable factor that must be taken into account. In order to be able to achieve these requirements, the fifth generation is required to increase spectral efficiency and to highly employ the spectral frequencies.[8] Finally, to achieve the vision of the new generation, the requirements must be matched with the market demands. In addition, it must overcome the limitations and drawbacks of previous editions along with improving their

technologies as well as services in such a way that the next generation adds new in the mobile world as Figure 3 depicts.

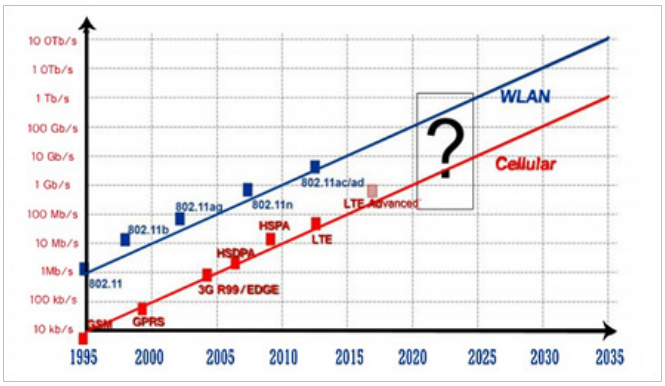

Figure 1 Wireless road map showing market entry of technologies.

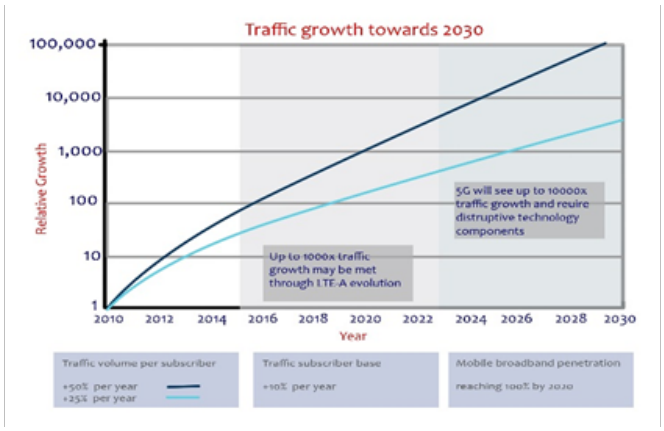

Figure 2 Prediction for traffic growth towards 2030.

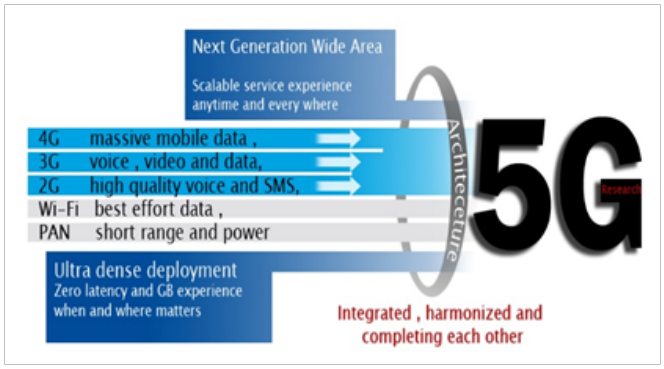

Figure 3 Integrating of existing services.

Fifth generation services and benefits

Next generation (NG) of mobile communication focuses on proposing new vision for several and hybrid types of services over the world based on telecommunication market's needs and it deals with high growth of traffic. Additionally, increasing the conventional bit rate for data, along with enhancing the internet services are the basic requirements of the novel version. Moreover, keeping and improving the quality of service (QoS) as well as deployment of massive connectivity and huge capacity are the important aspects of the new generation.[9]

Internet evolution and enhancements: Internet acts as an information bank. For the time being, most of people over the world use internet as an information source which supports them in all real activities. Based on huge capacity that will be available, a high speed connection among user requirements will be achieved. Also, 3D will be predicted to be applicable by 2020. Since 3D services represent the real world, end user will have a choice to select and decide to use these 3D services in the internet to save time and money. The most famous 3D services in the internet include 3D shopping, 3D games, etc. All enhancements in internet services will allow end user and human to change their life to become easier. Internet of things (IOT) reproduction, on the other hand, calls for wireless network densification and provides justification for transition to5G. Prediction of tens of billions of IOT and machine to machine (M2M) devices are presenting a unique set of demands from wireless network service. Smart city/home, smart grid, smart vehicle, e-health, emerging wearable's, wireless industry and logistics are some of the most important drivers for 5G.

Services adaptation: All services that will be accomplished and offered to different end users by the evolution of the next generation should be classified and adopted to the requirements of subscriber in terms of QoS. In this regard, all customers as well as end users use the same services in different ways in such a way that each subscriber is allowed to select his requirement that will pay for it. Some examples of these services are roaming, congestion, handover, etc. Operators or network providers should personalize these services for mobile individuals to be guided for their customer needs at specific time and place.[9] Moreover by 2020, one needs to implement and convert physical or environmental phenomena, such as location and weather, to become in information shape in order that they will be introduced as services to different users for their life to be enriched through better communication.

Mobility of connections: Nowadays, people over the world have many and different types and models of wireless communication devices like smart phones, note, tabs, etc. It is expected in the upcoming 5 to 8 years to have more and more people who will own a lot of wireless devices, equipment, sensors, smart home equipment, office equipment, etc. The major and main challenges are how to implement a new media of communication to be matched with all these devices for our life to be easier and subscriber can access all mentioned devices from any place in any time in such a way that services can be switched by the right way among all devices.

M2M communication networks: In this situation, we are going to propose one question which is how to implement this kind of communication for it to be reliable and flexible. Most of researches around the world succeeded to make M2M flexible and modernized technology. M2M can be founded through complementation of available widely technologies such as personal computers, internet and wireless sensors. It will play a good role in the infrastructure projects through decreasing the human intervention especially in daily problems like traffic in the very crowded cities. It can also support human by information and guide him to avoid any obstacles.

Fifth generation network components

In these times, different wireless technologies were founded, implemented and worked with different access and switching scenarios. As in the 2nd generation, it works based on circuit switching technique and the rest of newest generations are going to internet protocol (IP). IP means that all data and signalling will be carried and transferred through internet protocol of network layer.[10] IP acts as major and common factor for all. We propose that 5G will be user centric programme in mobile environment and different types of wireless mobile technologies available over the world that will give a

capability of subscriber to switch simultaneously different radio access techniques [RATs] from his single device. Then, we can implement new network nodes for policy based routing between IP tunnels to end user through different radio access techniques.[11] In this situation, we have two main issues for more explanation and realization of 5G network architectures. These issues are belonging to interoperability in non-homogenous networks and functional design architecture in mobile network. In the following, we will briefly discuss the general requirements of these issues.

Interoperability in non-homogenous networks: The major concept in non-homogenous networks is how to achieve and provide better connectivity in all time and keep on best QoS. This scenario will lead to emergence of vertical handover among different RATs.[12] Based on the heterogeneous wireless environment, it must pay more attention to how new designed system interworking via radio access techniques. The increasing of SE is a mandatory requirement. Also, it is required to maximize the batter power and achieve end user application by referring to user applications. Heterogeneous networks are classified as unified networks where the access of a single segment will take place through the connection with the application servers in and out network provider.[13] There are two possible models in order to be able to deployment these requirements among building segments and RATs.

Firstly, it is pointed to centralize access of network provider which will offer the integration between radio access technology and wireless access segment. Secondly, it tabulates the internet model for interoperability. This will support for continuous customer service, in case of independent RATs, to the mobile segment through network level connection.[14] The extreme goal of both possible models for interoperability is the same and it is providing a transparent transfer of user information between client applications and related server applications without impact on the diversity of access technologies. On the other hand, there may be a difference between the two models which is concerned with the method in providing interoperability. A part from this difference, the very important issue is what is known as vertical handover between access technologies and the conditions or circumstances which trigger this technology.

Functional Architecture of 5G Networks*:* The proposed system model designed for 5G network architecture of wireless mobile phone is displayed in Figure 4. This model is based on IP algorithm for both wireless and mobile network interoperability. The predicted designed system for 5G will contain an end user terminal and sum of independent radio access technologies. So, if we have access to four different RATs, we should have four different access specific interfaces to the mobile station (MS) in addition to simultaneous activation to all of them for the mentioned architectures to be functionally operated.[15,16]

Self-interference cancellation (Full-duplex)

Throughout time, we have a massive and different classification of wireless communication systems. People around the world need to use these systems in different applications, in an efficient manner, with the possibility of wide spreading of new wireless technologies in their life.

Interference and self-interference definitions

All types of wireless communication systems send and receive multiple types of signals based on the available frequency band, and this in turn leads to a huge number of propagated waves in free space. Interference is a combination of two or more propagated signals to generate composite waves, where these waves propagate at the same time and occupy some common frequency bands.[17] Because of this frequency cooperation, a constructive or destructive interference will result. Basically, interference is considered as one of the biggest problems in all wireless communication systems. It may yield to generate multiple unwanted issues such as crosstalk, noise in background, or drop calls which in turn lead to decreasing the key performance indicator for the used communication system. Interfering signals in wireless system can be classified into two categories: those caused by natural phenomena which are not within our capability to cancel out and those human made signals which can be attenuated and controlled. In existing wireless systems, we have different types of interference such as co-channel interference (CCI) which occurs between systems that use the same frequency band.[18]

In addition to adjacent channel interference (ACI), which emerged among geographically closed systems that employ neighbour frequency bands, there is another type known as multiple access interference (MAI), which is excited due to the transmission from multiple radios utilizing the same frequency resources to a single receiver. Moreover, there are other forms of interference such as inter symbol interference (ISI), self-interference (SI), and coexistence interference (CEI) and near end to far end radio interference, which exists only in mobile communication system.[19] Here, we are interested in SI only due to its role that it may play in system limitation. This category of interference occurs among transmitted signals from the same source which emits and receives on the same channel and at the same time. Also, non-ideal ties transceivers such as amplifier nonlinearities and IQ imbalance have the capability to generate SI. Multiple inputs multiple output (MIMO) technique can be considered as a source or a form of SI. Moreover, modulation schemes which are employed in communications can affect the amount of SI. In traditional wireless communication systems, we can transmit and receive on two separate channels in order to achieve the accepted performance parameters and keeping a satisfied level of QoS. NG technology of mobile communication is predicted to make more utilization for frequency spectrum in conjunction with full duplex (FD); through implementing single channel which is active both at time and frequency. It is predicted to improve SE along with increasing BW and data throughput. In the next, we will express more details regarding FD in addition to SI cancellation techniques.

Full duplex in wireless networks

FD allows user segment to send and receive signals at the same time over the same frequency. Also, FD overcomes several drawbacks of wireless communication systems. Additionally, FD enhances SE for cellular networks[20] as well as offers high transmission data rates. Moreover, it overcomes traditional transmission modes such as half duplex (HD), BW constraints. In addition to mitigation for any division duplex, it reduces the hidden terminal up to 88% and increases link capacity. Let us now take an example to consider one network consisting of three nodes X, Y, and Z. Both nodes X and Z are out of each other meanwhile both of them sending packets at the same time to node Y. These nodes can't detect a collusion that will occur, which demonstrate that FD can enhance the collusion detection among the network. Device to device (D2D) communication in heterogeneous networks is considered as one of the ultimate goals of FD in 5G, as Figure 4 illustrates. D2D permits user equipment such as mobile phone or any devices to communicate with other devices in short distances on requiring that low power consumption without routing to traditional base station (BS). The traffic routing in D2D communication should be off loaded from macro base station.[21–23]

Based on predicted higher data rate that will be offered or applicable as a result of evolution sequences, we should introduce this newest type of communication. Since D2D can successfully be accomplished without routing to macro BS as in conventional mobile systems, such scenario will generate one important issue which is how to charge or bill this type of service and how network providers deals with this scenario.

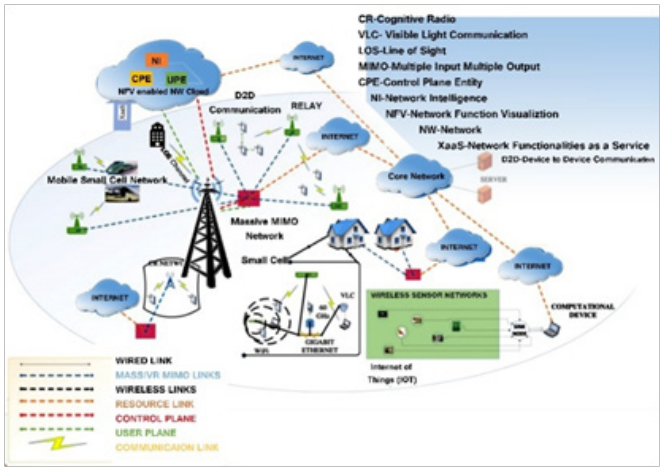

Figure 4 Functional architecture of 5G networks.

D2D communication in mobile networks

Mobile communication systems have been evolved many times through different techniques meanwhile D2D connectivity is not available. As network provider don't pay more attention to this type of communication, as well as cost reduction mentality, subscribers may not be interested to pay a lot of money to get this service. At the present time, we have a large scale of applications in addition to text services and voice applications. Also, location services along with low power communications over near devices will be considered. Based on available and upcoming trends in telecommunication markets, most of network providers thinking well to introduce and offer this type of services.[24] In other words, D2D communication can offer major changes in cloud computing. Moreover, this type of communication can support operators in network improvements especially in high density of users such as football events, and malls. The integration of D2D communication won't be easier, as we have some technical issues. The first one is that end user requires to communicate through different cellular networks with different RATs.[25] The second one is how to select the best transmission mode in order to keep on QoS.[26] The third major issue is CCI, which is caused as a result of D2D that will affect the key performance indicator of communication channel.[27]

As displayed in Figure 5, 5G mobile network is predicted to contain three grades: tier 5G mobile networks which are defined as macro tier, femto tier, and device tier. Macro tier located in normal connectivity from base station to devices. Femto tier found in D2D pair and D2D cluster connectivity. Device tier included D2D communication, and had different scenarios of connectivity.[28,29] Due to its importance, we will illustrate the D2D connectivity. This D2D has four major types. They are direct D2D communication with device controlled link establishment (DC-DC), direct D2D communication with operator controlled link establishment (DC-OC), device relaying with device controlled link establishment (DR-DC), and device relaying with operator controlled link establishment (DR-OC).[29] In the current situation, it should pay more attention to important object and thinking well of how network provider get revenue control payments charges from end user upon this type of communication since the network provider shall offer this service with high quality, good speed, available rate and high performance. Anyway, we think that the pricing of the mentioned classes of D2D communication will be categorized according to their offered services.

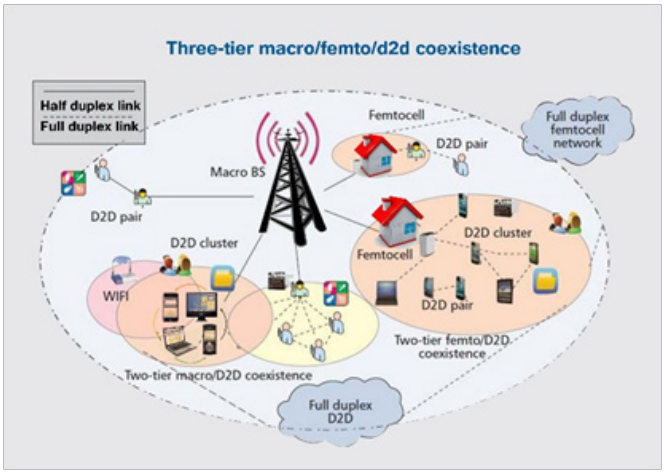

Figure 5 Developed FD-D2D communication in next generation of mobile communication.

Self-interference cancellation techniques

SI is a very serious factor that belongs to the development and improvement of FD communication system. The intensity of SI can be considered as one of the major challenges in the future of any full duplex communication system. This is due to those problems caused by simultaneously transmit and receive signals on the same frequency channel. Applicable and conventional wireless communication systems have the capability of choice since it can act as transceiver simultaneously either on different frequency bands (FDD) or on the same frequency band with different time (TDD). FD allows the possibility of increasing SE as well as the capacity will be folded through cancellation of time/frequency constraints in the case of up and down transmission links. In order to take the advantages of the above mentioned scenario of FD, wireless communication systems must simultaneously be sent and received by using the same frequency channel in order to achieve single channel full duplex.[3] In the same direction, SI has indirect proportional to FD gain; as an example, suppose we have one wireless device; the SI of which will be very high since the power generated from transmitting antenna is greater than that obtained by receiving antenna which is coming from conventional base station or other wireless devices.[20] The previous work in this regard shows that it is very important to measure and reduce the amount of SI in order to increase the gain of FD communication system.[30,31] SI cancellation techniques can be tabulated in two main categories which are called passive cancellation and active cancellation. The total SI cancellation requirements are basically based on the implementation methods and can be reached more than 100dB for the full gain in FD communication system to be achieved.

Passive SI improvement: In passive algorithm, suppression can be implemented through three antennas; two for input and one for output (MISO). Placement of transceiver antennas on the same

device employs major and effective solution to attenuate the power of SI.[32] Figure 6 depicts the restoration of this technique which can be realized by considering two antennas for transmission, with calculated distance of separation "d" and "d+λ/2" far from receiving antenna, and one at the receiving end. The two transmit antennas can attain null position which means that the two waves are offset. In other words, the transmit antennas will add destructively to cancel out each other, causing a null position where receiving antenna receives a much weaker signals.Passive technique can offer suppression for SI in the range of 20-30dB.[33] On the other hand, passive suppression with three antennas has some problems and limitations such as the request of three antennas and difficult far field effects that doesn't adapt to environment. By integrating the single antenna with two feed points, as shown in Figure 7, the antenna has the capability of propagating and receiving signals with polarization diversity. It is important to note that the feeding points are orthogonal and have the same amplitude. This type of SIC can offer isolation up to 40dB. The proposed technique has three major motivations as improving the power efficiency, overcoming limitations of FD communication and reducing interference between wireless devices. To achieve more improvement for SI, we should implement the above techniques with both RF and digital cancellations which results in active category of cancellation.

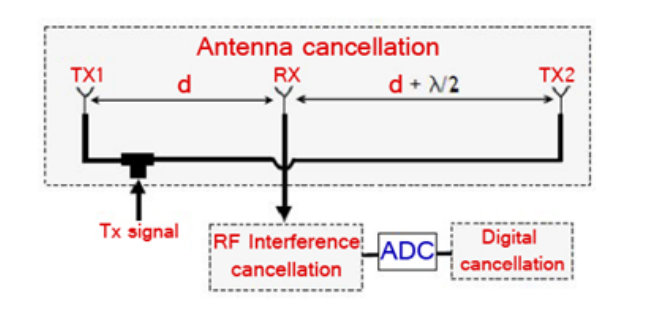

Figure 6 Implementing several antennas for passive suppression.

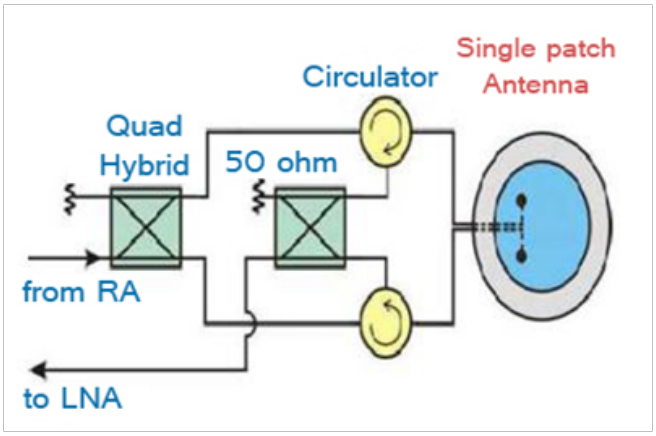

Figure 7 Single antenna with balanced Feed.

Active cancellation techniques: Active suppression technique is based on achieving single channel in FD communication system, in which both analogue and digital algorithms are included. Through combination of RF cancellation and digital processing, we are able to exploit and enhance FD transceivers. The main idea of active suppression is the subtraction of the SI signals from the received version.[35] The subtraction process will be carried out through analogue and digital samples. Different types of active SI suppression actually exist and can be considered as a part of analogue and RF cancellation because subtraction process takes place before analogue to digital conversion process. Active SIC in FD system can be carried out by using balanced to unbalanced conversion which is called Balun. Inverse SI signal which is the output of Balun will be useful to cancel SI as Figure 8 illustrates. Balun algorithm will receive a positive signal from the transmitted antenna, which generates SI signal, and this signal will be inversed through this processing. Both received and inversed signals will be combined together. Also, some modifications can be implemented on the inversed signal, such as delay and attenuation, in order to be matched as far as possible to the received signal. QHx220 noise suppression chip is used to eliminate the known version of analogue interference from the received signal.[36] Balanced to unbalanced cancellation technique can provide suppression for SI till 45dB. Moreover, it is not affected by increasing band width and power. There are other techniques that can be realized to reduce SI which belongs to RF interference cancellation mixed with a combination of attenuators and phase shifter as displayed in Figure 9. Many different suppression techniques are summarized in Table 2, which focus on the intensity of SI that can be suppressed through each technique.

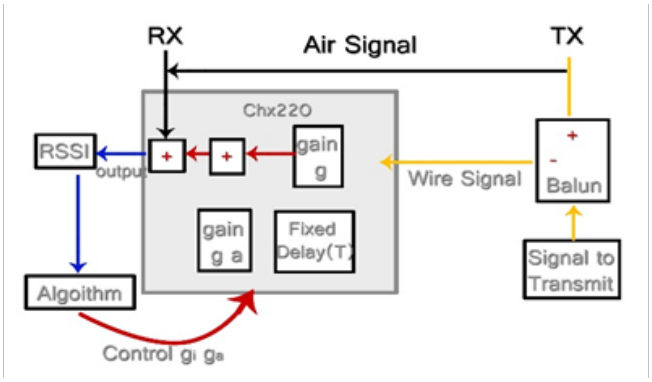

Figure 8 Active SIC using Balanced to unbalanced converter.

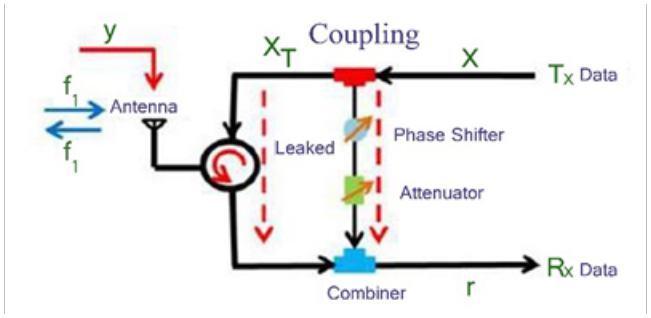

Figure 9 RF cancellation technique.

Table 2 SIC range according to each technique

SIC techniques	SIC range
Antenna Isolation	20-30dB
Analogue cancellation	20-45dB
Digital cancellation	25-30dB
Total suppression	113dB

Conclusion

Next generation of mobile communication is predicted to offer new features as massive connections, decreasing the latency down to 1ms and increasing the speed of data rate up to 10Gbps. Widening full duplex communication to a longer range could remain a primarily challenge due to increasing the spectral efficiency along with more utilization of frequency spectrum. The intensity of SI can be suppressed through the combination of passive and active cancellation techniques. Dual polarized antenna procedure will predict to overcome SI issue owing to the fact that the processing of polarization determines the direction of radiated electric field vector. Moreover, the transferred energy will be vanished due to the orthogonal polarization of the waves.

Acknowledgements

The authors received no financial assistance for the research.

Conflict of interest

The author declares no conflict of interest.

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Citation: Mashade MBE, Hegazy EA. Predicted characteristics of 5g version of mobile communication and self-interference cancellation in full duplex radio. *Electric Electron Tech Open Acc J.* 2017;1(1):20–27. DOI: 10.15406/eetoaj.2017.01.00005