Advances in Networks
2017; 5(1): 14-21
http://www.sciencepublishinggroup.com/j/net
doi: 10.11648/j.net.20170501.12
ISSN: 2326-9766 (Print); ISSN: 2326-9782 (Online)

Review Article

Active and Passive Self-Interference Cancellation Techniques for Full-Duplex Systems in the Next Generation (5G) of Mobile Communication Networks

Mohamed B. El_Mashade[1], Ashraf Aboshosha[2], Ehab A. Hegazy[1]

[1]Electrical Engineering Dept, Faculty of engineering, Al_Azhar University, Nasr City, Cairo, Egypt
[2]NCRRT, EAEA, Nasr City, Cairo, Egypt

Email address:

ElMashade@yahoo.com (M. B. El_Mashade), editor@icgst.com (A. Aboshosha), Ehab.hegazy@gmail.com (E. A. Hegazy)
*Corresponding author

To cite this article:

Mohamed B. El_Mashade, Ashraf Aboshosha, Ehab A. Hegazy. Active and Passive Self-Interference Cancellation Techniques for Full-Duplex Systems in the Next Generation (5G) of Mobile Communication Networks. *Advances in Networks.* Vol. 5, No. 1, 2017, pp. 14-21.
doi: 10.11648/j.net.20170501.12

Received: March 22, 2017; **Accepted**: April 15, 2017; **Published**: October 16, 2017

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 Fifth Generation Networks. While in the existing version of mobile networks the available spectrum is not sufficiently used, the predicted version will use that spectrum in 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 future.

Keywords: Self-Interference Cancellation, Fifth Generation, Frequency Division Duplex, Time Division Duplex, Antenna Design, System Design, Passive Suppression, Radio Access Techniques

1. Introduction

Global system of mobile communication has many developments starting from 1980 (1G) passes by many modifications till 2010 that resulted in 4G. These versions introduce many services including voice, text, and multi-media. 3G & 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, longer battery life for low power devices, five times reduce end to end latency and user data rate which is higher 10 to 100 times than the existing one. Fifth generation till now has no unique definition [1] and it is expected to be in use in 2020.

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 down link to achieve the performance requirements (Key performance indicator), which means that the system must operate at half duplex mode where it can't TX and Rx on the same frequency band. Since self-Interference will appear and destroy everything in the communication system, 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].

It is of importance to try to eliminate the phenomenon of self-interference in order to attain the goal of single channel. So, some techniques must be searched to overcome this problem and achieve the lowest value for the self–interference value to a level which shouldn't be larger than the desired signal. This minimization must be implemented in Antennas system, RF part, and Analog &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 concerns with active cancellation [6].

The rest of the paper is organized as follows. Section II is concerned with introducing Fifth generation vision and technology overview. Section III will explain and clarify the available techniques that support to improve and reduce the amount of self-interference which is generated by using any full duplex in communication system.

2. 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. In the following, we are going to discuss some aspects associated with this topic.

2.1. Vision and Requirements

Global system of mobile communication first 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 frozen into a set of standards known as the "GSM specifications". The functionalities regarding evolved technologies started 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 which is considered an enhanced version in the internet services in mobile world. Finally, 4G or LTE was existed. Moreover, LTE provides enhanced user experience for broadband wireless networks and supports scalable BW from 1.25 MHZ to 20MHZ. Furthermore, it provides 100Mbps as downlink peak rate and 50Mbps peak rate for uplink along with enhancing the latency to be less than 100ms in control plane and less than 5ms for user plane [7].

Through the sequence of editions displayed in Figure 1 We can define the fifth generation vision as means of how address and classification of telecommunication can market needs in future or at least in next five years from current days. In the predicted version, we need to increase the connections from mega to be giga, along with increasing traffic volume in conjunction with Figure 2 [8]. Additionally, speed to become 10Gbps for data rate and decreasing latency to be 1ms are the necessary modifications in 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. Moreover, it must overcome the limitations and drawbacks of previous editions along with improving their technologies as well as services in such a way for the next generation in to mobile world as shown in Figure 3.

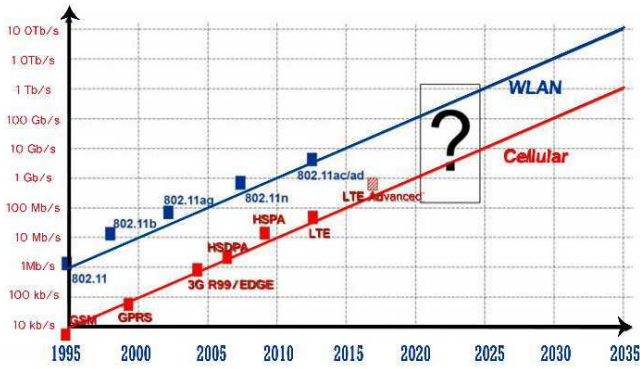

Figure 1. *Wireless Roadmap, showing market entry of technologies [38].*

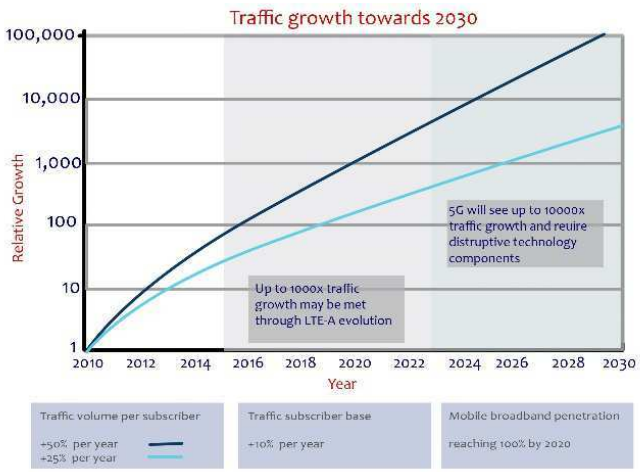

Figure 2. *Prediction for Traffic Growth towards 2030 [8].*

2.2. Fifth Generation Services and Benefits

Next Generation of mobile communication focuses on proposing new vision for several and hybrid types of services over the world based on telecommunication market needs and it deals with high growth of traffic. Additionally, increasing 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 next generation [9].

2.2.1. Internet Evolution and Enhancements

Internet acts as 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, it will led to high speed

connections between user requirements. 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 [9]. 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 be easier. Internet of Things (IoT) reproduction calls for wireless network densification and provides justification for transition to 5G.

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 important drivers for 5G.

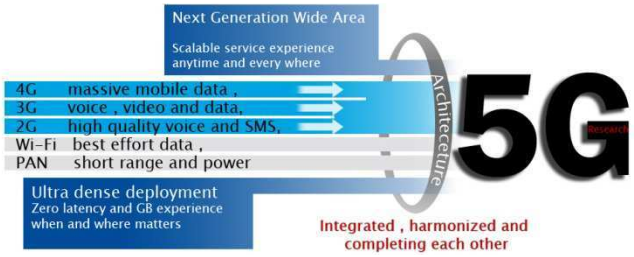

Figure 3. *Integrating of existing services [8].*

2.2.2. Services Adaptation

All services that will be accomplished and offered to different end users by the evolution of next generation should be classified and adopted to the requirements of subscriber in terms of QoS; even though all customers as well as end users used the same services in different ways, which allow each subscriber 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 to 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 to be in information shape such as location and weather to become introduced as services to different users in order to enrich his life through better communication.

2.2.3. 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 any time in such a way that services can be switched by the right way between all devices [9].

2.2.4. M2M Communication Networks

In this situation, we have one question which is how to implement this kind of communication 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 [9].

2.3. 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]. Now we have two main issues for more explanation and realization of fifth generation network architectures. These issues are belonging to interoperability in non-homogenous networks and functional design architecture in mobile network of 5G.

2.3.1. 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? Mentioned requirement will lead to emergence of vertical hand over 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 and user applications. Heterogeneous networks are classified as unified networks and 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 deployments mentioned 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 [11, 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 application servers without impact on the diversity of access technologies. On the other hand, it can find a difference between the two models which is concerned with the method in providing interoperability. Apart 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.

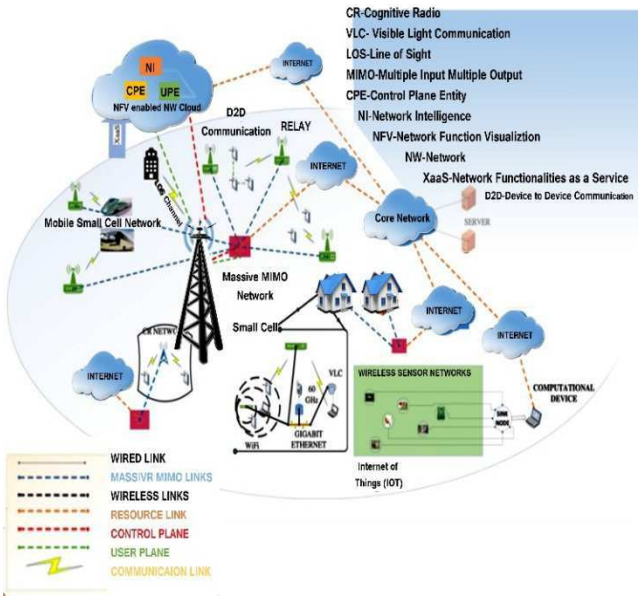

Figure 4. *Functional Architectures of 5G Networks.*

2.3.2. Functional Architectures of 5G Networks

The proposed system model designed for 5G network architecture of wireless mobile phone is displayed in Figure 4, which is based on all IP model 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. 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 with the aim of function of mentioned architectures [15, 16].

3. Self–Interference Cancellation-Full Duplex

Throughout time we have a massive and different classification of wireless communication system. People around the world will complete in using these systems in different applications in addition to the widespread of new wireless technologies in their life.

3.1. Interference and Self-Interference Definition

All types of wireless communication systems send and receive multiple number of signals based on frequency band, which lead 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 propagated at the same time and occupy some common frequency bands [17], which will lead to constructive or destructive interference. Basically, Interference is considered as one of the biggest problems in all wireless communication systems. It may lead to generate multiple issues such as cross talk, noise in background, 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 found between systems geographically close to each other and using neighbour frequency bands, multiple access interference (MAI), which appears among the transmissions from multiple radios utilizing the same frequency resources to a single receiver. Moreover, there are other types of interference such as inter symbol interference (ISI), SI, coexistence interference (CEI) and near end to far end radio interference, which found only in mobile communication system [19]. SI that includes interference which occurs among transmitted signals from single transmitter which are transmitted and received on the same channel and at the same time. Also, non-idealties transceivers such as amplifier nonlinearities and IQ imbalance have the capability to generate SI. Multiple input multiple output (MIMO) technique is considered as a source or a form of SI. Moreover, modulation schemes which are used in communication system 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 on 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 the time and frequency [2]. It is predicted to improve SE along with increasing BW and data throughput.

In the following, we will express more details regarding FD in addition to SI cancellation techniques.

3.2. Full Duplex in Wireless Networks

FD allows user segment to send and receive signals at the same time over the same frequency. Also, FD overcome several drawbacks of wireless communication systems. 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, reduces the hidden terminal up to 88% and increases link capacity.

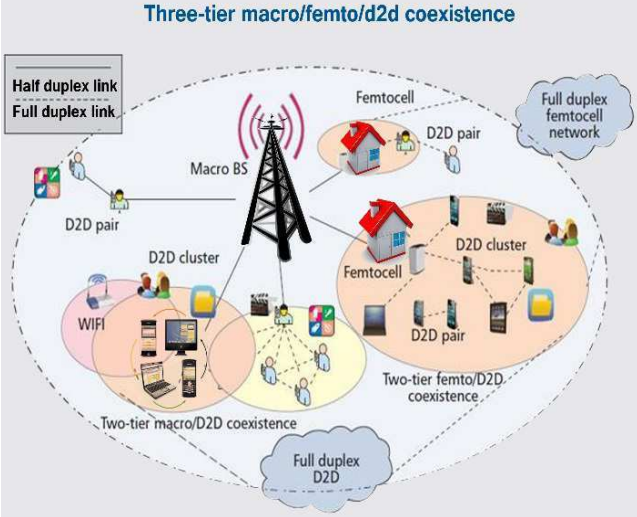

Figure 5. *Develop FD-D2D communication in Next generation of Mobile communication [33].*

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 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 offloaded 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.

3.3. 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 is 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]. In the following 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. Any way, we think that the pricing of the mentioned classes of D2D communication will be categorized according to their offered services.

3.4. 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 above mentioned scenario of FD, wireless communication systems must simultaneously be sent and received by using same frequency channel 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 SI of which will be very high since power generated from transmitted antenna is greater than that received 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.

3.4.1. Passive SI Improvement

In passive technique, suppression can be implemented through three antennas; two for input and one for output (MISO). Placement of transceiver antennas on the same device employ major and effective solution to attenuate the power of SI [32].

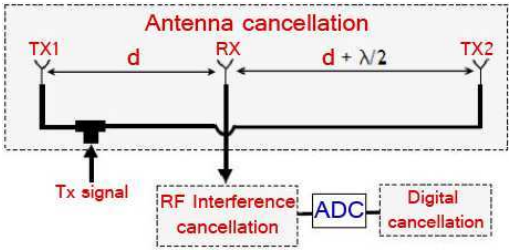

Figure 6. *Implementing several Antennas for passive cancellation [36].*

In Figure 6 is depicted to the restoration of this technique which can be realized by considering two antennas for transmission, with calculated separated distance 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 the two waves are offset [33]. In other words the transmit antennas will add destructively to cancel out each other, causing a null position where receiver antenna hears a much weaker signals.

Passive technique can offer suppression for SI in the range of 20dB to 30 dB [33].

Passive suppression with three antennas has some problems and limitations such as need three antennas, limited to 802.15.4. Moreover, difficult far field effects and doesn't adopt to environment.

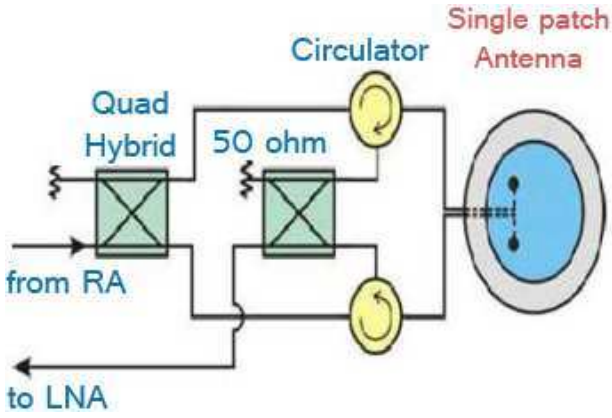

Figure 7. *Single antenna with balanced Feed [6].*

By integrating the single antenna with two feed points as showed 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 same amplitude.

This type of SIC can offer isolation up to 40 dB. The proposed technique offers 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 cancellation and digital cancellation which resulting in active cancellation techniques.

3.4.2. Active Cancellation Techniques

Active suppression technique employs a major part to achieve single channel in FD communication system, in such a way that includes both analogue and digital techniques. Through combination of RF cancellation and digital processing, we are able to exploit and enhance FD transceivers. Active suppression techniques work based on subtracting the SI signals from the received signal [35]. The subtraction process will be carried out through analogue and digital samples. Different types of active SI suppression are actually existing 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 achieved 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 illustrated in Figure 8 [36]. Balun will receive a positive signal from transmitted antenna which generates SI signal, which will be inversed by balun. Both received and inversed signals will be combined together. Also, some modifications can be implemented on the inverse signal, such as delay and attenuation, in order to be matched, as far as possible to received signal. QHx 220 noise suppression chip is used to eliminate known analogue interference signal from received signal [36].

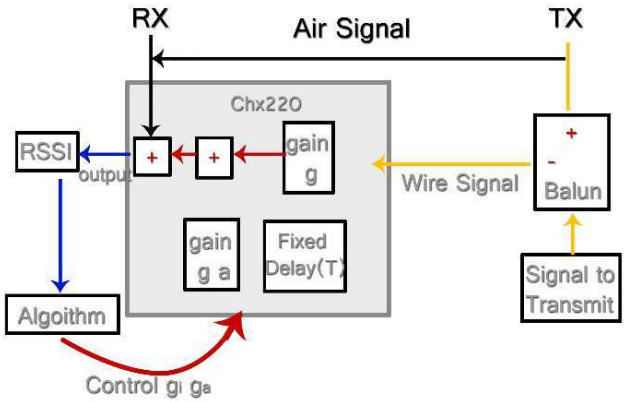

Figure 8. *Active SIC using Balanced to unbalanced converter [36].*

Balanced to unbalanced cancellation technique can provide suppression for SI till 45dB. Moreover, it is not affected by increasing bandwidth 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 [37].

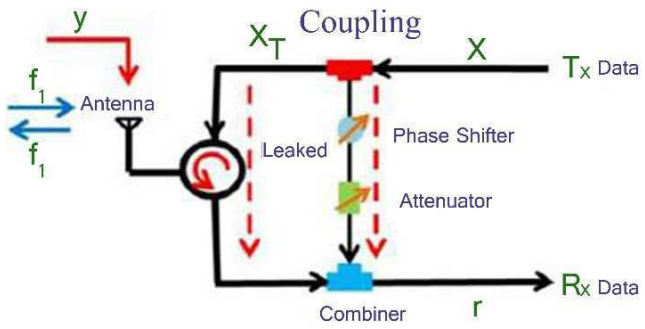

Figure 9. *RF cancellation technique [37].*

Many different suppression techniques are summarized as shows in Table 1, which focus on the intensity of SI that can be suppressed through each technique.

Table 1. *SIC range according to each technique [33, 36].*

SIC Techniques	SIC range
Antenna Isolation	20-30dB
Analog cancellation	20-45dB
Digital cancellation	25-30dB
Total suppression	113dB

4. Conclusion

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

References

[1] J. G. Andrews, S. Buzzi, W. Choi, S. V. Hanly, A. Lozano, A. C. K., Soong, and J. C. Zhang, "What will 5G be?" IEEE J. Sel. Areas Commun, vol. 32, pp. 1065–1082, Jun. 2014.

[2] A. Goldsmith, "Wireless Communication", Cambridge Univ. Press, 2005.

[3] J. Choi et al., "Achieving Single Channel, Full Duplex Wireless Communication," ACM MOBICOM 2010, Chicago, IL, 2010.

[4] D. Bharadia, E. McMilin, and S. Katti, "Full Duplex Radios," ACM SIGCOMM 2013, Hong Kong, 2013.

[5] J. I. Choi, M. Jain, K. Srinivasan, P. Levis and S. Katti, "Achieving Single Channel, Full Duplex Wireless Communication," The 16th Annual International Conference on Mobile Computing and Networking (Mobicom), September. 2010.

[6] Michael. E. Knoxl, "Single Antenna Full Duplex Communications using a Common Carrier," in Wireless and Microwave Technology Conference (WAMICON), 2012IEEE 13th Annual, April. 2012.

[7] 4G Wireless Video Communications Haohong Wang, Lisimachos P. Kondi, Ajay Luthra and Song Ci © 2009 John Wiley & Sons, Ltd. ISBN: 978-0-470-77307-9.

[8] Nokia Networks-white paper-5G use cases and requirements.

[9] Outlook: visions and research directions for the wireless world, WWRF, oct. 2011.

[10] T. Janevski "traffic Analysis and design of wireless IP networks", Artech House Inc., Boston, USA, 2003.

[11] T. Janevski "5G Mobile phone concept"-CCNC conference in Las Vegas, 2009.

[12] M. Kassar, B. Kervella, G. Pujolle "An overview of vertical hand over decision strategies in heterogeneous wireless networks" Elsevier computer communications 31, p. 2607-2620, 2008.

[13] W. Luo, E. Bodanese, "optimizing Radio Access in a Heterogeneous wireless network Environment" IEEE International conference on communication, Dresden, Germany, 14-18 June 2009.

[14] M. Ha Nguyen Tran Hasegawa, Y. Murata, H. Harada, "representation of user satisfaction and faimess evaluation for user- centric dynamic spectrum access" personal, indoor and mobile Radio communication (PIMRC), Tokyo, Japan, 13-16 September 2009.

[15] Vadan Mehta "5g Wireless Architecture" By Vadan Mehta.

[16] Akhil Gupta, R. K. Jha, a Survey of 5G Network: Architecture and Emerging Technologies. Aug 2015 · IEEE.

[17] Stavroulakis, P., "Interference Analysis of communication systems" IEEE Press, New York, 1980.

[18] H. Holma and A. Toskala, *HSDPA/HSUPA for UMTS*. Wiley, 2007, 268 pages.

[19] J. Andrews, "Interference cancellation for cellular systems: a contemporary overview," IEEE wireless communications magazine, Vol, 12, no. 2, pp, 19-29, april. 2005.

[20] X. Xie and X. Zhang, "Does Full-Duplex Double the Capacity of Wireless Networks," Proc. IEEE INFOCOM '14, May 2014, pp. 253–61.

[21] S. Ali, N. Rajatheva, and M. Latva-aho, "Full Duplex Device to Device communication in cellular Networks," Proc. EuCNC, Bologna, Italy, June 2014.

[22] D. Feng et al., "Device –to-Device communication in Cellular Networks," IEEE Commun, Mag., Vol, 52, no. 4, 2014, pp. 49-55.

[23] L. Wang, H. Tang, and M. Cieerny, "Device –to-Device Link Admission Policy based on Social Interaction Information, IEEE Trans. vehic., no. 99, 2014.

[24] D. Astely et al., "LTE Release 12 and Beyond," IEEE commun. Mag, Vol. 15, no, 7, 2013, pp. 154-60.

[25] A. T. Gamage, H. Liang, and X. Shen, "Two time-scale cross – layer scheduling for cellular /WLAN interworking" IEEETrans. On communication, Vol. 62, no. 8, pp. 2771-2789, Aug, 2014.

[26] 3GPP TS 36.300: "LTE; Evolved universal terrestrial radio access (E-UTRA) and evolved universal terrestrial radio access network (E-UTRAN); Stage 2" Rep. V 11.6.0, 2013.

[27] J. Wang et al., Resource sharing of under laying device to device and uplink cellular communications, IEEE Commun. Lett., Vol. 17, no. 6, pp. 1148-1151, June 2013.

[28] *Li Wang, Fei Tian, Tommy Svensson, Daquan Feng, Mei Song, and Shaoqian Li* Exploiting Full Duplex for Device-to-Device Communications in Heterogeneous Networks IEEE Communications Magazine • May 2015.

[29] Mohsen Nader Tehrani, Murat Uysal, and Halim Yanikomeroglu, "Device to Device communication in 5G Cellular Networks Challenges, Solutions, and Future Directions" IEEE Communications Magazine • May 2014.

[30] A. sabharwal et al., "In -Band Full Duplex Wireless: Challenges and Opportunities, "arXiv: 1311.0456, 2014.

[31] D. Bharadia, E. McMilin, and S. Katti, "Full Duplex Radios," Proc. ACM SIGCOMM, Hong Kong, 2103, pp. 375-86.

[32] Zhongshan Zhang, Xiaomeng Chai, Keping Long, Athanasios V. Vasilakos, and Lajos Hanzo Full Duplex Techniques for 5G Networks Self-Interference Cancellation, Protocol Design, and Relay Selection IEEE Communications Magazine • May 2015.

[33] Li Wang, Fei Tian, Tommy Svensson, Daquan Feng, Mei Song, and Shaoqian Li Exploiting Full Duplex for Device-to-Device Communications in Heterogeneous Networks IEEE Communications Magazine • May 2015.

[34] E. Everett et al., "Empowering Full- Duplex Wireless Communication by Exploiting Directional Diversity," Asilomar Conf. signals, systems and computers, 2011, pp. 2002-06.

[35] E. Ahmed, A. M. Eltawil, and A. Sabharwal, "Self-Interference Cancellation with Phase Noise Induced ICI Suppression for Full-Duplex Systems," to appear Global Telecommunications Conference (GLOBECOM 2013), December 2013.

[36] M. Jain, J. I. Choi, T. Kim, D. Bharadia, K. Srinivasan, S. Seth, P. Levis, S. Katti, and P. Sinha, "Practical, Real-time, Full Duplex Wireless," in Proceeding of the ACM Mobicom, Sept. 2011.

[37] Phungamngern, N, Uthansakul, P.; Uthansakul, M. "Digital and RF Interference Cancellation for Single-Channel Full duplex Transceiver Using a Single Antenna," 10th International Conference on Electrical Engineering / Electronics, Computer, Telecommunicatins and Information Technology (ECTI-CON), pp. 1 – 5, 2013.

[38] G. Fettweis, et al., "5G Personal Mobile Internet beyond What Cellular Did to Telephony" IEEE Comm. Magazine, pp. 140-145, Feb. 2014.