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Performance Evaluation of a Massive MIMO Intercell Interference Prediction Method

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ABSTRACT

This paper presents a massive MIMO intercell interference prediction method. Despite the deployment of 4G in Lagos, Nigeria urgently needs to upgrade to a 5G network in order to quickly meet the demand for a wide range of multimedia services. The downstream and uplink data capacities of 5G networks are no less than 300 and 60 Mbps, respectively, with a penetration rate of at least 95% at any moment of time; Based on the local data of Huawei Nigeria Co., Ltd. in Lagos, Nigeria, a 5G intercellular interference prediction scheme based on LTE performance index is proposed. The performance of the currently deployed LTE network is evaluated using performance metrics such as uplink and downlink capability, and a possible intercellular interference mitigation technology is recommended for the deployment of 5G network in Lagos. The identified key performance indicators include air simulation, carrier jamming to noise ratio, RLC peak throughput, coverage probability, and map-based model. The static inter-cell PFR algorithm has good CINR coverage for low CINR values (near the cell edge), while the Hard FFR algorithm has good CINR coverage for high CINR values (near the central region). While large-scale antenna systems will allow for all-digital array architecture, which helps to maximize beamforming flexibility, But the cost is a major challenge with the evolution of the pilot affecting pollution with general SINR constraints, limits being able to create the correct beam pattern using a large number of elements, it is necessary to adjust the phase and amplitude of each antenna unit and configure the antenna beam to control full digital processing and redistribution. The relatively poor performance in Fig. 2, Fig. 3 and Fig. 4 indicates that there is no coordination algorithm in the network, which also affects the network OTA performance. In summary, in order to improve the spectrum efficiency and system throughput, it is recommended to use the static intercell interference technology for future deployment of the 5th generation system in Nigeria.

KEYWORDS

Inter-cell interference; LTE; Massive MIMO; Multiple access technique; Non-orthogonal.

1. Introduction

Fast development in wireless communication, high demand for broadband mobile communication and the advent of nascent wireless multimedia applications is responsible for the improvement of wireless broadband access technologies (Hicham et al., 2015). However, the ever increasing multimedia services compel telecommunication operators to put some constraints on the use of the spectrum, which resulted in more inter-cell interference (ICI); thereby creating traffic bottleneck in telecommunication network infrastructure allocation (Islam et al., 2013). A key factor in cellular network deployment strategies is addressing system's performance with respect to common metrics such as spectral efficiency, degree of coverage or outage probability (Richter and Fettweis, 2010). Massive MIMO (Multiple Input, Multiple Output) has over the past few years become one of the leading research topics in wireless system (Marzetta and Ngo, 2016). Scaling up MIMO to hundreds of antenna elements reportedly promised unprecedented increase in spectral and energy efficiency and the current standardization efforts target up to 64 antenna ports (Fodor et al., 2017); thus enhancing higher user demands (Bhattacharyya and Bhattacharya, 2013).

Despite the development of the long-term evolution (LTE) technology, there is serious need for higher spectral efficiency, and this was necessitated by the ever growing demand for internet access for application in Internet of things (IoT), cloud computing, virtual reality, autonomous driving, wireless cloud-based office, and machine-tomachine connectivity. ICI is the key difference between a cellular communication system and non-cellular communication, and it allows for high peak data rates, with a tempting desire to use the entire spectrum in every cell (Intelligence, 2014).

Some of the requirements that have been identified by operators of the fifth generation (5G) include 1 to 10 Gbps connections to end points in the field, latency delay of 1 millisecond, a thousand times bandwidth per unit area (with between ten and a hundred times the number of connected devices, an approximately 100% perception availability), 100% area coverage, 90% network energy reduction usage and a ten-year battery life span (at low power usage). Efforts are on to explore technical solutions for a 5G system that could use frequencies above 6 GHz and up to as high as 300 GHz. However, higher frequency bands have been reported to offer smaller cell radii and thereby, achieving widespread coverage by using a traditional network topology model present a serious challenge in order to achieve these set of requirements (Cai et al., 2017). Understanding the inter-cell interference mitigation technique is therefore necessary to further improve the spectral efficiency of the 5G network when using massive MIMO.

This paper presents a prediction model on inter-cell interference in massive MIMO mitigation, considering various Non-orthogonal multiple access technique (NOMA) in a typical 5G network in Lagos, Nigeria. Although, LTE network is yet to be fully deployed in Nigeria, there is need for concerted efforts to be directed at limiting some of the identified challenges in preparation for the eventual deployment of the 5G technology. NOMA technique of inter-cell interference coordination is an emerging research subject, and its importance can not be overemphasized. More so, the traditional orthogonal frequency division multiplexing (OFDM) has been found to be inadequate in satisfying demands required for 5G networks. Again, since sensor nodes often transmit diverse forms of data asynchronously for narrow bands, OFDM systems will anticipate the synchronization of various subsystems in order to avoid serious signal interference between adjacent sub bands.

2. LITERATURE REVIEW

A number of modulation techniques have been proposed in the literature to address some of the various problems encountered in a typical 5G network. Among these are signal filtering, pulse shaping, and precoding (which was introduced to mitigate out-of-band (OOB) OFDM signal leakages). Filtering has been identified as the most straightforward approach to reduce the OOB leakage of OFDM signal and, with a properly designed filter, the leakage over the stop-band can be greatly suppressed according to Cai et al. (2017). It was reported by Hussain et al. (2016) that time division multiple access (TDMA), frequency division multiple access (FDMA), orthogonal frequency division multiple access (OFDMA) as well as other multiple access techniques do not provide good capacity efficiency because frequency and time are limited; hence there is need to search for new techniques such as Code Book-Based Multiple Access Scheme, Sequence-Based Multiple Access and Beam Division Multiple Access (which has being proposed for Massive MIMO) in order to improve the channel capacity and efficiency.

Channel state information (CSI) was recognized as one of the most tasking challenge in modern wireless communication system because it requires large number of antennas at both the transmitting and receiving stations. This is to enable easy the deployment of time division duplex (TDD) technique owing to the presences of several cells, which results in pilot contamination, which is another challenge encountered in satellite system (de Lamare, 2013). But when considering massive MIMO, the capacity boundary is usually calibrated as a complex entity because of simultaneous multiuser arrangement which are projected to allow as much as 300 Mbps of data rate and possibility of 60 Mbps for both the downlink and uplink channels respectively, for every proposed location and region (Hossain, 2014). The most challenging task is the expected ability to deliver peak throughput for the downlink channel per connection of 10 Gbps and with latency capacity of less than 1 microsecond. This is coupled with a projected estimation of area capacity density of 1 Tbps; thus offering connection capacity of hundred times when compared with LTE systems (Global Mobile Suppliers Association, 2015).

On June 29, 2016, one of the mobile telecommunication network providers in Nigeria won the frequency spectrum license for the 2.6 GHz band as the sole bidder in the auction exercise by the Nigerian Communications Commission (NCC), as reported by Global Mobile Suppliers Association (2015). Nigeria is one of 28 African countries currently offering 4G LTE services. The penetration rate is restricted to only a few major cities such as Lagos and Abuja. In 2017, this same network service provider signed another Memorandum of Understanding with Ericsson for collaboration on the rollout of 5G infrastructure as a trial; with the expectation of commercial deployment before the year 2020 (Sangar et al., 2016). A proposal towards future research was initiated by Sangar et al. (2016) in anticipation of achieving efficient joint collision avoidance control methods aimed at satisfying some objectives such as, maximizing system throughput, balancing traffic load to 30 a minimum signal to interference ratio for high priority, which when combined with conventional cell association methods, will satisfy the required objectives by reducing inter-cell interference. Also, Katranaras et al. (2009) recognized an hybrid cell association method, combined with prioritized power control. They subsequently proposed a set of new modulation techniques that can be employed in the next generation of cellular networks with the possibility of determining the best modulation technique to reduce inter-cell interference in a multi antenna array propagation system.

Again, according to Khansefid and Minn (2015), the new macro pico feature of the LTE Het-Net system is encumbered with fast data speed challenges which makes the data transfer process much higher than previous 2G and 3G systems, with resulting interferences that negatively impacts data transmission process (inter-cell interference), and these are directly related to the uplink and downlink interferences, amongst others.
Furthermore, Li et al. (2014) submitted that the limitation emanating from the uplink interference from the mobile to macro base station. The losses that occur in uplink interference results in several power losses (Kyosti, 2018). The authors further observed that the only way to overcome the two properties is to reduce the downlink interference, which occur due to the signaling between data transmission from base station to the mobile station on one hand, and the power loss due to signaling, on the other hand. Kyosti (2018) extended the generalized cellular system to compare various system scenarios and their effect on capacity with single

antenna at each base station. The efforts resulted in higher capacity when a system with multiple receiving antennas was considered with its perfectly directional antennas and sectored cell coverage.

Also, Ding et al. (2017) acknowledged that increased received power is obtained when the multiple base station antennas are considered omnidirectional and uncorrelated with each other or when the directivity gain of the directional antennas is considered larger than unity. Zhu et al. (2020) showed that by exploiting the low-dimensional structures of optimal beamforming can have a low complexity, which was observed to be independent of the number of transmit antennas. Again, Saih et al. (2020) proposed a channel-estimation scheme that employs comprehensive knowledge of large-scale gained by applying an orthogonal pilot reuse sequence to eliminate pilot contamination in edge users with reduced channel quality, based on the approximation of large-scale fading. The findings of the simulation indicate that improved channel approximation and reduced performance loss, which could lead to a high data rate.

Furthermore, Bandopadhaya et al. (2021) proposed machine learning to predict the network performance of a massive MIMO HetNet system considering a multi-cell scenario. It was discovered that the coverage probability and area spectral efficiency were within the tolerable range for practical applications. Du et al. (2021) employed a new joint maximum-ratio and zero-forcing (JMRZF) precoding scheme, where part of APs (access points) are combined to perform centralized zero-forcing (ZF), while other APs apply simple maximum-ratio transmission (MRT). It was shown that the max-min power controls improved the spectral efficiency significantly when compared to the uniform power control scheme. Lopez-Perez et al. (2021) provided an overview of the state-of-the-art on the fundamental understanding and practical considerations of the energy efficiency challenge in 5G networks, and found out that there is lack of accurate models for batteries, whose capacity reduces with time, and this affects the overall energy efficiency and costs.

Additonally, it was observed that increasing the number of sectors in each cell to a very high value tends to yield a finite value. Again, when joint processing of all the receivers was considered for a cellular media access control by sectorization, the highest capacity from the system was not achieved when the directional antennas do not reach their maximum ideal performance due to inter-cell interference. There is urgent need for substantial research work to be undertaken on the application of massive MIMO to 5G network, especially in promising developing economies, like Nigeria, with high demand for an efficient and affordable last mile communication network. Nigeria is the most populous country in Africa with well over 200 million people; hence digital communication is a key requirement for such country to unlock its potentials.

3. Materials and Methods

The data for 4G performance which was sourced from Huawei Nigeria, and was used to model the inter-cell interference prediction for 5G system. The overall path loss and shadowing are not explicitly modeled by any empirical formulas or distributions, as is the case in the majority of channel models. Instead, they are determined implicitly by the contribution of propagation paths of both the uplink and down link traffic parameters. Determination of prediction pathways and for path segments among others are believe to enhance better rate of successes of 5G systems.

The system flow chart for the prediction is shown in Figure 1. For simulation purpose, seven evolved node of the base station (eNodeBs) around Lagos area are randomly selected in the focused zone and five of the eNodeBs are used. Basically, eNB is the only mandatory node in the radio access network of LTE (Hassan and Gao, 2019). The eNodeB is a complex base station that handles radio communications with multiple devices in the cell and carries out radio resource management and handover decisions. Each eNodeB consists of three hexagonal sectors, such that each hexagonal sector is served by a different directional antenna as shown in Table 1.

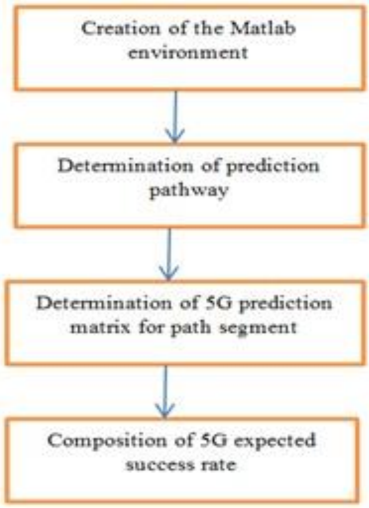

Figure 1. Flow chart of the prediction process

$Iinter{-}cell = \sum Lml{=}1.m{\neq}n\ Pl\ g((mnj))llx(m)l$ (1)

Where the subscript (m)l and superscript (nj)l represent the index of the transmitting antenna at the base station and user, respectively. g(nj) is the information symbol intended for the j-th user in the same cell.

Over the air emulation

According to Hassan and Gao (2019), the uplink data traffic is comparable to the conducted emulation such as the uplink average throughput, such that the transfer function is constructed, not only by the customer edge (CE) router and cables, but also by probes. Device under test (DUT) is a device that is tested to determine performance and proficiency. Device under test may be a component of a bigger module or unit known as a unit under test, or device under test antennas and the environment within the AC. The base station superimposes users' messages by assigning corresponding power coefficients, denoted by $\alpha i,\ i \in$ {1, 2}. Power-domain NOMA (PD-NOMA) was reported by Tavares et al. (2014) to assign higher power to users with poor channel conditions, which is expressed as:

$H\ (t, f) = F\ (t, f)\ W\ (t, f)$ (2) The first term is a transfer matrix of the physical environment (within AC) from K probes to NDUT antennas, and it is defined as:

$F\ (t, f) = \{\psi n,\ k(t, f)\} \in CN \times K$ (3)

where $Grx,\ n$ and $Go,\ k \in C1 \times 2$ are the polarimetric antenna pattern vectors of nth device under test vector, the distance and the path loss term between the kth probe and the nth device under test.

The main emphasis in a faded over-the-air (OTA) emulation would be to satisfy the condition:

$H' = H$ (4)

Such that it perfectly reforms the targeted MIMO radio channel capacity. Mathematically, this could be obtained by determining F as shown in equation (5).

$W\ (t, f) = F\ (t, f) - 1H'\ (t, f)$ (5)

Equation (4) can only be achieved theoretically by using equation (3). However, the OTA transfer matrix F (t, f) is not typically measurable (or otherwise determinable), neither for antennas nor frequency, as represented in the DUT, as obtained in Table 2.

Carrier to Interference plus noise ratio

The carrier to interference plus noise (CINR) is the ratio of the carrier signal of the best serving eNodeB for a user among neighbor eNodeBs. All the interference plus noise is shown in equation (6), as presented by Hassan and Gao (2019):

$PM,k\ Gm,M,k$

$CINR =$ (6)

$N0\Delta f + \sum M' \quad PM' \quad ,kGm,M' \quad ,k$

$PM,\ k$ and $PM' \ ,\ k$ are the transmitted power of serving eNodeB M and neighboring eNodeB M' on sub-carrier$k$, as shown in Tables 1 and 2 respectively. $Gm,\ M,\ k$ is channel gain between macro user m and serving eNodeB M on sub-carrier k . Channel gain from neighboring eNodeBs are denoted by $Gm,\ M' \ ,\ k$. Where No is white noise spectral density and Δf is sub-carrier spacing.

Coverage probability

From the coverage probability with respect to Tables 1 and 2 when considering the data as obtained according by Tavares et al. (2014), it is evident that the probability of a mobile user is able to achieve some $SINR$ threshold, such that its complement's cumulative distribution function (CCDF) can be written as:

$Coverage\ probability = P\ (SINR > H)$ (6)

Table 1. Sample eNodeB position in Lagos Metropolis for simulation

Site Name	Site ID	Longitude	Latitude
Ajah	LAG902	3.62574	6.47151
Osapa London	LAG921	3.464752	6.445559
Newroad	LAG925	3.47085	6.45843
Sangotedo	LAG926	3.502176	6.437708
Abijo	LAG930	3.52405	6.45087
Monastry	LAG941	3.47449	6.42697
Awoyaya	LAG967	3.5447	6.4315

Table 2. Characteristics of a typical channel

Parameters	Numbers
Number of eNodeBs	7
Sector per eNodeBs	3
Channel Number	1765
E-UTRA Band	3
Power (dbm)	43
Antenna model	65deg/17dbi1/800MHZ
Channel bandwidth	20MHz
Number of resource blocks	100
Spectrum of resource blocks	180 KHz

Number of sub-channels	1200
Subcarrier spacing	15 KHz
Noise figure (DB)	5
Number of antenna port Transmission	2
Reception	2

Where, P is a function of the established success rate and the drop call rates, H is the resultant of both the uplink and down link average throughput. Generally, the right-hand side of equation (6) represents the coverage probability parameter and the $SINR$ is greater than some $SINR$ threshold, H (Tavares et al., 2014).

4. Results and Discussion

Figure 2 is a map based model of the performance of the OTA emulation. It shows the plot of the coverage probability against the physical downlink shared channel carrier to interference plus noise ratio (PDSCHCINR) link. Figure 2 demonstrates the concept of partial frequency reuse. From Figure 2, for 10 dB PDSCHCINR threshold, the coverage probability is 0.4 dB for no intercell interference coordination (NOICIC), 0.5 dB for hard fractional frequency reuse (hard FFR), 0.2 dB for soft frequency reuse (SFR), 0.1 dB for soft fractional frequency reuse (SFFR) and 0.3 dB for partial frequency reuse (PFR). This implies that 72% of the coverage area receive greater than 10 dB carrier to interference plus noise ratio (CINR) under the PFR algorithm. As a result, when carrier to interference plus noise ratio is decreasing (close to celledge), using PFR is recommended as a static algorithm. This finding agrees with Bai et al. (2019).

Again, a map-based model of the behavioral display of the performance of the carrier to interference plus noise ratio is displayed in Figure 3. This plot shows the relationship between the coverage probability and peak radio link control (RLC) throughput for the down link. Figure 3 illustrates the static inter-cell interference scheme performances. Also, the probability of coverage by peak RLC channel throughput under different static interference coordination algorithm is compared. Hence, considering a random point, where peak RLC channel throughput is 20 Mbps. For instance, the probability of coverage for SFR is at 0.4 dB, 0.3 dB for Hard FFR, 0.2 dB for SFFR, 0.1 dB for NOICIC and 0.5 dB for PFR.

Furthermore, Figure 4 shows LTE drop rate in percentages and established success rate in kbps; thus revealing the best static inter-cell interference mitigation technique. Also shown in Figure 4 is increased interference for center-users in neighboring sectors. This is because, NOICIC algorithm totally partitions the whole cell into three sectors and there is no sharing of resource blocks between users of neighboring sectors as observed

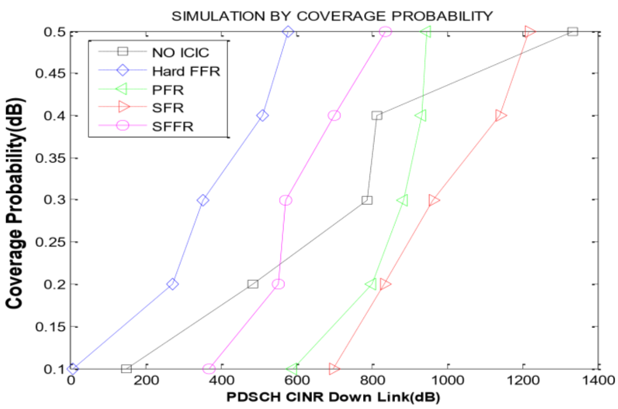

Figure 2. Coverage probability vs PDSCH C/ (I+N) threshold

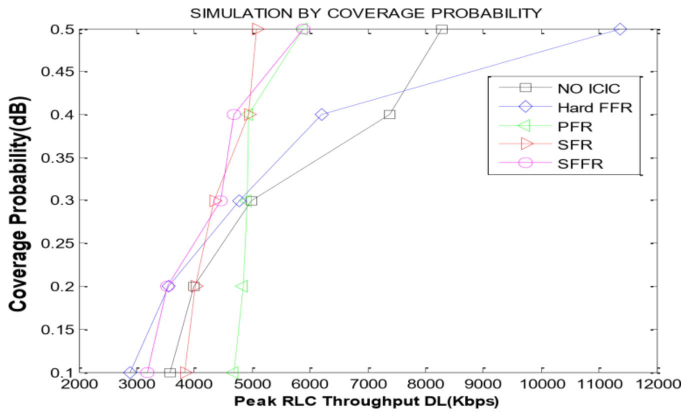

Figure 3. Coverage probability vs peak RLC channel throughput

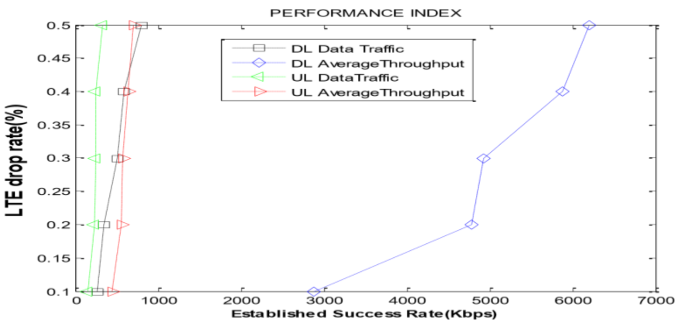

Figure 4. LTE performance index

Frequency domain resource partitioning technique was investigated by Papadopoulos et al. (2016). This method can be deployed by assigning different carriers to eNBs, or by using different OFDMA sub-carriers for transmission, such that the simplest form is hard frequency reuse, where nearby eNBs use orthogonal frequency carriers. However, hard frequency reuse seldom results in the best performance for LTE. An alternative to this is fractional frequency reuse or soft frequency reuse. Another approach is cloud empowered cognitive inter-cell interference coordination scheme, as presented by Shen and Letaief (2015). This is an adaptive model which unifies the evolving phantom cell and cloud radio access network concepts; wherein the scheme is complemented by exploiting a channel state information aware thresholdbased cognitive interference protection. This scheme restricts the interference from the individual co-channel small cell transmitters to remain below a prescribed threshold value.

5. Conclusions

This paper presented a proposed 5G inter-cell interference prediction scheme that employs LTE performance index by using locally sourced data from Huawei Nigeria limited in Lagos, Nigeria. The LTE network deployed in Lagos currently adopts an intercell inteference coordination (NOICIC) technique, which probably accounted for the relative poor performance. Because this method has low average downlink throughput. The deployment of the static ICIC algorithms will encourage better CINR coverage rather than using NOICIC algorithm as it is presently deployed on most LTE networks in Nigeria.

Furthermore, static intercell PFR algorithm has better CINR coverage for low CINR values (near cell-edge), while Hard FFR algorithm gives better probability of coverage for high CINR values (near center region). Although the massive antenna system will allow full digital array structure which helps to maximize the beamforming flexibility, cost is however a major challenge. This is due to the use of one separate radio frequency chain for each antenna element. Again, implementing static ICIC schemes on the 5G network in Lagos can improve the average downlink throughput than what is currently obtainable with the 4G network.

A major setback in modern wireless systems is the need for acquisition of CSI in a timely manner. TDD had been observed to offer the most suitable alternative to acquire CSI because the training requirements in a TDD system is independent of the number of antennas at the base station (or access point) and there is no need for CSI feedback. With the evolving effects of pilot contamination with the general SINR constraints, which limit the ability to create the right beam pattern using massive element, it is essential to calibrate the phase and amplitude of each antenna element and configuration with full digital processing of both the antenna beam control and MIMO. The relative poor performances observed in Figures 2, 3 and 4 are pointers to the absence of coordination algorithm, which also affects the OTA performance of a network. To sum up, static intercell interference technique is proposed for future deployment of the fifth generation system in Nigeria in order to enhance higher spectral efficiency and system throughput.

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