Proceedings of the International MultiConference of Engineers and Computer Scientists 2016 Vol II,
IMECS 2016, March 16 - 18, 2016, Hong Kong

Interference Mitigation for Femto Deployment in Next Generation Mobile Networks

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Abstract **- The huge capacity requirements for the next generation mobile network is defining the technologies that will drive the future system. The trio of millimeter wave, massive MIMO and small cell are emerging as the tripod upon which the upcoming network is expected to thrive. With about 80% indoor mobile usage, small cell and by extension, femtocell is projected to deliver the bulk of the predicted mobile traffic. This paper takes an overview of the future 5G network and advances solutions to the most anticipated interference challenges as a result of cell densification.**

Keywords **- 5G, Femtocell, Massive MIMO, Millimeter wave, Small Cell**

I. INTRODUCTION

Wireless evolution is yet again at the verge of another generation. The year 2020 has been the most forecasted take-off date [1], [2], [3]. This follows the evolutionary trend of mobile networks since its inception in the early 1980s. A new generation has emerged approximately every 10 years [2]. Succeeding generations have seen the introduction of additional mobile services, leading to increased number of users and traffic expansion. As more devices get connected with diverse mobile applications, the resultant increase in traffic places a huge burden on the network, necessitating demands for higher system capacity. More bandwidth allocation has been the usual means of meeting higher system capacity demands [4], [5]. The continual reduction of Radio Frequency (RF) spectrum available for wireless communications is now a problem for future network expansion. With the present 4G now widely deployed and contending with a looming capacity limit challenge, the natural big question becomes what next? Current researches are emerging independently that tend to aggregate a technological direction for the next generation mobile networks (5G) [6]. Majority of the discussions are coming to almost a consensus on some key technologies. Broadly, three big 5G technologies have been identified: massive Multiple-Input Multiple-Output (MIMO), Millimeter wave (mm-Wave) frequency and Cell-Densification (small cell) [2].

II. REVIEW

Why will 5G be different?

The usual incremental approach to system capacity will fall short of meeting enormous demand needs by 2020. The projected figures are daunting. The massive volume of data, huge numbers of connected devices and data rates on demand are all growing exponentially [2].

Manuscript received December 23, 2015; revised January 5, 2016.
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Already recent studies predict a mobile broadband traffic growth of up to a factor of 1000 by the year 2020. It assumes a 10 times increase in the number of subscribers and 100 times higher traffic per user per day [4], [7].

There are about 7 billion devices with wireless connectivity presently in use by means of heterogeneous deployments. This number is expected to be surpassed by the time 5G comes on stream as subscribers base grow between 10- and 100-fold due to many new applications beyond personal communications [8]. One of the new applications is the much canvassed Internet of Things (IoT), which would be yet another disruptive demand on wireless networks. Device interface would move from human-centric to machine type, such as surveillance cameras, connected sensors and smart homes etc [9]. As available spectrum is continually been depleted whereas the primary device for internet connection is steadily becoming wireless, rigorous studies to find ways of providing greater capacity beyond the current 4G has become imperative [10], [11].

Three Key Enablers for 5G Technology

Researches on the upcoming 5G networks suggest that the system would not be defined by a specific technology. It is been projected that the next generation of wireless networks will integrate multiple technologies in order to meet the diverse requirements of the future networks such as spectrum, data rates and ultra dense cell structure. This paper believes that in order to the meet the predicted 1000x system capacity, the future 5G networks must combine base station (BS) density, Spectrum and performance efficiency at least ten times those of current 4G. Fig. 1 shows how this can be attained.

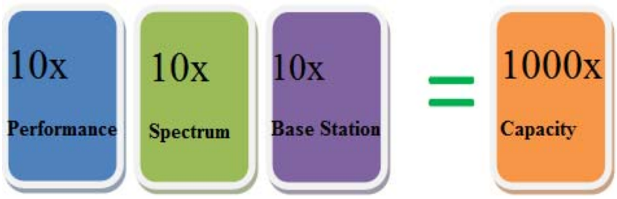

Fig. 1. BS density x Spectrum x performance efficiency = 1000x 4G system capacity

Millimeter Wave mm-Wave

Between now and 2020 when the next wireless network is expected, the main 3rd Generation Partnership Project (3GPP) bands of 2600, 2100, 1800 and 900 MHz would have been consumed by LTE and High Speed Packet Access (HSPA) capacity upgrades. To tackle the impending capacity crunch, spectrum beyond 10 GHz and potentially up to 100 GHz will be required. This makes high frequency bands a very promising solution for future wireless backhaul. The deployment of millimeter wave bands will

ISBN: 978-988-14047-6-3
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

TABLE I
TRANSMIT POWER LEVELS IN MASSIVE MIMO

Transmission Scheme	**Freq. (GHZ)**	**No. of Tx antennas**	**No. of streams**	**Beam-forming gain (dB)**	**Tx power/ stream (dBm)**	**Tx power/ antenna (dBm)**	**Total Tx power (dBm)**
16X16 MIMO	11	16	16	0	25	25	37
Massive MIMO	20	64	16	6	24	18	36
		256	16	12	18	6	30
		1024	16	18	12	-6	24

present abundance of spectrum and make it an attractive requirement for 5G networks. The total allocation potential is up to 300 GHz in the mm-W band with 5 GHz, 7 GHz, 10 GHz, 15 GHz and even 20 GHz of available bandwidth. To handle the volume of small cell traffic, as much spectrum as 10 GHz bandwidth, is available in the 70-85 GHz band [12]. However, losses due to rain at 28 GHz could reach as much attenuation as 7 dB/km for a rainfall as heavy as 25 mm/hr (roughly 1 inch per hour), though this could reduce to about 1.4 dB if coverage area gets to within 200 m radius [10]. The channel bandwidth for current 4G networks is limited to 20MHz. Expanding channel bandwidth far beyond 20MHz would lead to increased data capacity, whereas allowing for significant reduction in latency for digital traffic.

Millimeter wave bands will lead to the deployment of massive MIMO in smaller cell structure. Smaller cell size would imply more base stations with the attendant cost implications. But as table 1 [27] shows, the use of massive MIMO (with antennas numbering up to tens or hundreds) results in less transmit power and increased signal processing. This means that deployment of smaller size cells would greatly reduce BS transmit power and hence cost. Therefore, small cells with higher frequency and diversity gains of large antennas arrays will result in higher data rates and enhanced capacity which overall, provides a better system solution.

Consider that higher order spatial reuse is a requirement to enhance capacity and service quality for cellular architecture of the next generation. It is worthy to note that the use of small cells reduces the average distance between transmitters and users, which leads to lower propagation losses and higher data rates [10]. Enhance spectral reuse via device cooperation holds enormous benefits such as mitigating complex interference in an ultra dense network of the kind expected by 2020 [2].

It is a common myth that rain and other atmospheric incidence negatively impacts on the performance of the spectrum. Another strong case for cell densification comes here - the design environment. A cell size on the order of 200m can withstand the issues of atmospheric absorption. This implies that under all likely conditions the spectrum can support a sufficiently good power budget performance within a 200m range. At 28 GHz and 38 GHz, mm-W spectrum for cell dimensions on the order of 200m does not suffer significant path loss due to atmospheric absorption [10]. Small cell therefore will compliment the utilization of mm-Wave. It can be deduced from table II that mm-Wave is potentially beneficial to Pico and Femto cell types.

Massive Multi-Input Multi-Output (MIMO)

Multiple-Input Multiple-Output technique has been in use for existing 4G wireless networks. In order to enhance cellular systems capacity, range and reliability, the technique basically exploits the space dimension [13]. The unique challenges associated with mm-W band such as poor link budget due to high path loss and higher dispersion effects are prompting this novel thinking. To compensate for the loss, massive MIMO antennas are estimated to be as much as 10 times the number of streams in service to all terminals. This could mean the deployment of more antenna elements in the region of tens to hundreds, which enables the achievement of considerable beam-forming gains whereas serving many more users in parallel [14]. The poor propagation characteristic of mm-W band is the strongest attraction for the deployment of massive MIMO [15].

Experimental results have shown that the compression of higher order antenna elements against the shorter wavelength of the mm-W bands compensates for the increased path loss. Densification and deployment of higher frequency bands makes Massive MIMO a marketable choice for the future 5G networks. Furthermore, in massive MIMO systems, the effects of noise and fast fading vanish, and intra-cell interference can be mitigated using simple linear pre-coding and detection methods [11].

Small Cell

The Mobile Telecommunications industry has already started pursuing the idea of more dense networks by means of heterogeneous deployments in 4G systems [9]. Yet much denser deployments appear to be an attractive solution towards attaining throughput and coverage enhancements in achieving the envisioned 1000x capacity in 5G [16], [17], [2].

This heterogeneous architecture consists of hierarchical multi-layer deployment of cells with different footprints. Such deployments include a macrocell overlay network with extra tiers of densely deployed small cells such as micro, pico and femtos [18]. Table II illustrates typical values of the different characteristic of base station cell types. Femto Access Point (FAP) is a portable piece of equipment that acts as a mobile base station to enhance coverage and connectivity, mostly indoors. Femtocell (coverage area of FAP) radius ranges up to 20 meters [19]. FAP has low cost and power-saving advantages, which is ideal for small cell [20]. This feature makes femtocell attractive to the next generation of mobile networks, which will comprise of ultra dense networks. But dense networks can be prone to interference due to the creation of additional cell boundaries. The users around cell edges may experience poor signal quality and degraded connectivity.

TABLE II
CELL TYPE CHARACTERISTICS

CELL TYPE	SCENARIO	CELL RADIUS	POWER RF (dBm)
Femto	Indoor	10m – 20m	10mW
Pico	In/Outdoor	200m	250mW
Micro	Outdoor	500m	5W
Macro	Outdoor	> 1km	40W

Spectrum is costly, so using separate carriers on adjacent small cells as a solution is ruled out. Because of the role femtocell is expected to play in 5G small cell network, section IV of this paper will focus on interference mitigation in a FAP deployed small cell. Appropriate interference mitigation schemes are to be devised and applied in order to avoid a degrading system performance in an ultra dense femtocell network [17].

There is an important symbiosis between the three key 5G drivers. Small cells by their size are advantageous to the huge potentials of mm-Wave spectral bands despite the high RF Path Loss (PL) which increases with frequency. The high-frequency mm-Wave suffers huge attenuation penetrating solid materials such as walls. Hence its application is best for short distances and indoors [11]. Also large beam-forming gains derivable from large antenna arrays of massive MIMO can enlarge coverage at longer ranges to mitigate millimeter wave PL. Lower mobility of small cells compensates the reduction in channel coherence time at millimeter wave. Furthermore, higher frequencies with shorter wavelength such as those of mm-Wave are attractive to massive MIMO transceivers designs because the physical size of the antenna array would be reduced [6].

III. FEMTOCELL BASIC ARCHITECTURE

The Access Configuration

FAP is customer deployed equipment whose access method can be categorized into three: Open, closed and hybrid [21]. Fig. 2 shows femtocell basic architecture with core network and macrocell interface.

1. Open Option: grants every user within signal range access to connect to the network.
2. Closed Option: restricts access to only subscribed users
3. Hybrid Option: Grants limited access to nonsubscribers such as data only.

Small Cell for Higher Capacity

Femtocell offers the shortest distance between Transmitter and Receiver. Its deployment improves signal quality and boost system capacity. This paper agrees with [19] that Shannon’s law supports this logic in its description of the wireless link capacity (in bits/s) in a bandwidth W Hz to the Signal-to-Interference-plus-Noise Ratio (SINR).

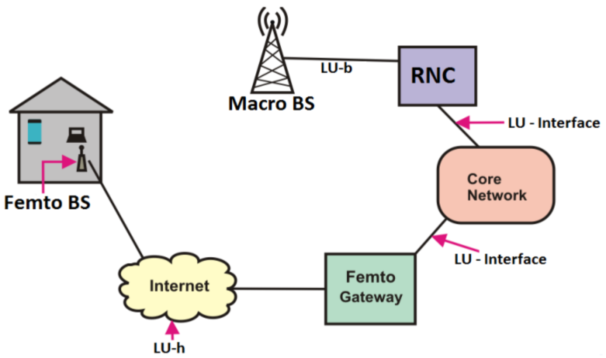

Fig. 2. Femtocell Basic Architecture

On its part, SINR is determined by the transmission power, path losses and shadowing during propagation. Increase in path loss weakens the transmission signal as $Ad^{-\alpha}$. Where

A = fixed loss,
d = distance between transmitter and receiver,
α = path-loss exponent.

Capacity increases as the distance (d) and path loss exponent (α) gets smaller, which can best be achieved in a small cell Base Station type.

Multiple utilization of femto BS as against one pico BS can increase indoor capacity by as much as a factor of 10 to 100. The high capacity result is derived from the elimination of coverage shadow often associated with larger cell types. This is possible because femtocell radii are between 10% and 30% of those of picocells [28].

From available wireless usage data, the indoor/outdoor usage ratio scenario is about 80:20 [11]. In designing the 5G architecture, careful distinction must be made of indoor and outdoor scenarios. Such separation is vital so that penetration loss through building walls can be put on check. Millimeter-wave signal has propagation limitations towards non-line-of-sight regions. To overcome this deficiency, massive MIMO will assist in exploiting diversity in order to enhance performance.

IV. INTERFERENCE MANAGEMENT

5G and Femtocell

The reuse of spectrum enhances efficiency but increases the possibilities of interference. The different nodes in Heterogeneous Network overlay, while transmitting to each other create complicated interference situations [22]. Co-channel interference therefore, remains a major hindrance for 4G, which makes an efficient interference management scheme indispensable for any future wireless network. The unplanned nature of femtocell deployment in the future 5G, can cause interference contaminated spots as a result of the several small cells within close range [9]. This could lead to overall poor levels of performance and frustrates the high capacity 5G targets.

As a solution to co-channel interference for 5G, this paper supports Advance Interference Management (AIM) model of [23]. It is a better idea to utilize a combined or joint interference management model instead of confining

ISBN: 978-988-14047-6-3
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

interference mitigation to network side alone as implemented in 4G. Under this scenario the Network side performs a joint scheduling interference management which is complemented by the User Equipment (UE) side advance receiver interference management. Fig. 3 shows significant throughput gains derivable from a joint scheduling of interference management.

Interference Scenarios in Femtocell

This paper agrees with [24] in the identification of possible femtocell interference scenarios

1. *Same frequency: Femto interferes with Macro base station (Cross Layer)*
   Interference may arise if some femtocells within a macrocell utilize the same frequency channel. The femtocells may interfere with the macrocell signals and diminish the network performance.

2 *Same frequency: Macro interferes with Femto station base station (Cross Layer)*
   A reverse of the above situation may arise. Here the macro interferes with femtocell signals.

3 *User equipment multiple base stations interference (Cross Layer)*
   Signals from User Equipment intended for femtocell may arrive at a macrocell station and create interference Or that intended for a macrocell may arrive at a femtocell and cause interference

4 *Signals of Femtocells in close proximity interfere (Co-Layer)*
   With the ad-hoc and unplanned nature of femtocells, devices that are located in very close proximity may interfere by creating background noise that will reduce the sensitivity of femtocells.

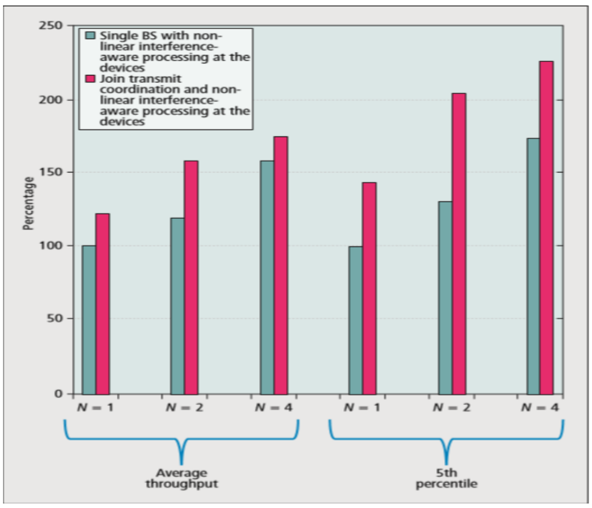

*Fig. 3. Gains of combining the effects of nonlinear and intra and inter cluster interference into devices with 1, 2 and 4 antennas [26].

Power control algorithms and radio resource management are schemes that have been applied to mitigate interference. Application of these techniques avoids jamming of signals of users [21].

An integration of Cognitive Radio (CR) and Stochastic Geometry are the technologies to deliver this solution. CR enables a femto base station within the dense network to autonomously identify (time-frequency) radio resources unoccupied by macro-cells and by using such unoccupied resources, inter-tier interference would be mitigated. To understand the geometric positions of each cell, stochastic geometry is utilized. Stochastic geometry is used to tell the position and link of each node in a given network. In order to determine the geometric locations of each cell, stochastic geometry provides a novel means of modelling the distances between base stations. Results indicate that this model can facilitate femto-BSs acquisition of more reliable information about the environment and raise the spatial reuse within the Macro-BS requirement [25].

In order to effectively forestall interference, FAP will need coordination and synchronization with the macrocell base station. Femtocell networks should be structured to adopt self organizing capabilities that support timing recovery protocols. Installation of global positioning system in FAP will help synchronization with the macrocell base station as discussed in [19].

V. CONCLUSIONS AND FUTURE WORK

A good way to improve capacity of a wireless link is to reduce the distance between transmitter and receiver. That is what femto deployment in a small cell network achieves. Users will experience superior signal quality and prolong battery life. Femtocell with its largely indoor scenario attracts higher system throughput due to a number of other factors such as low user mobility and less fading.

Small cells derive huge gains by diminishing the propagation losses prone to mm-Wave whereas massive MIMO allows multiplexing of users with controlled interference. The integration of Millimeter wave frequency, massive MIMO and small cell is the way to go in the next generation wireless networks. Since penetration losses do insulate the FAP from other nearby femtocell transmissions, it makes this portable equipment even more ideal for interference avoidance schemes. This paper advocates the hybrid option for the future femtocell deployment.

With appropriate application of interference cancellation, suppression and avoidance techniques, interference can be mitigated sufficiently as to boost system capacity towards attaining 5G goals.

Even as there are good prospects for the future 5G networks, more attention should be given to finding better integration of femto, WiFi and the promising Visible Light Communications (VLC). This could further unlock opportunities for much higher system capacity and coverage expected in the next generation of wireless networks.

A challenge for the proposed self organizing network would be the overhead that may result and its impact on the overall system performance, which deserves adequate investigation. Interference management in femtocell is important if the high capacity target of 5G networks is to be realized.

ISBN: 978-988-14047-6-3
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

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*Fig 3 used with the author's (Federico Boccardi) permission for [26]