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HYBRID LTE- FRACTIONAL FREQUENCY REUSE (FFR) IN USER MOBILITY ENVIRONMENT

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ABSTRACT

Long Term Evolution (LTE) is broadly available to the world. The upcoming trend in LTE-Advanced (LTE-A) emphasizes the enhancement in spectrum efficiency, capacity and cell-edge user throughput and thus highlights the small cell technologies. With the advantage of small size, Femtocell is able to be deployed at "Died zone" and thus satisfying the service expectation particularly to cell-edge users. Femtocell is also an inexpensive compact base station to increase mobile operators' capacity and coverage at the same time increases users' data throughput. With the increase of small cells in the network, the proposed Fractional Frequency Reuse (FFR) which intelligently reuse the spectrum helps to mitigate Inter-Cell Interference (ICI), at the same time, improve spectrum efficiency. A hybrid topology which incorporated Femtocell and FFR is analyzed in this paper. The available spectrum is divided into four ranges and reused intelligently. The hexagonal cells are further divided into inner and outer regions. Inner region radius and resource is intelligently controlled to achieve maximum performance and user fairness. The performance of the system is observed over a short period of time by considering users' mobility.The system is improved and User Satisfaction (US) is maintained at high level over a period of time.

Keywords: fractional frequency reuse, long term evolution-advanced, femtocell.

INTRODUCTION

Wireless service is achieved through simple Macrocell signaling traditionally. Although the Macrocell is upgradable, generally coverage areas cannot be expanded. For example, the most traffic generator is from indoor, while indoor signal quality is by nature the worst for a single tier system (here is where most of the blind spot zones found). The network capacity and data throughput depends on the signal quality. Therefore, it is useless even if one may suggest having Macrocell to allocate more resources for indoor usage. Furthermore, in conjunction with the high investment in Macrocell, the increment of indoor cellular demand as reported in (Per H. Lehne, Telenor) shows that 60-80% of traffic is generated indoor. This eventually urges the cellular operator to seek for more efficient and more cost effective solution. A few alternatives such as Distributed Antenna System (DAS) Network (Saleh, A. A. M. *et al*., 1987) small cell technologies are emerged to diminish their anxiety. The coexistence of Macrocell network with DAS and other small cells are known as "Heterogeneous network" or "HetNet"(Jeanette Wannstrom. *et al*., 2012). Unlike relay station, which plays the role to amplify, decode and forward the signal (Jaafar, A., *et al*., 2012), small cell technology also further expends the network coverage and improve data rate.

Femtocellis the rebranding technology invented over centuries with few disadvantages or loop holes. The problem brought over from last century pressured the new extensive Femtocell implementation strategy to concentrate on the autonomic system and operational cost reduction. With the cell size reduced (indirectly indicates number of cells increased), growing traffic and complex network highlights the needs for Femtocell revolution in minimizing the cost and autonomic system. Research in (Claussen, H., *et al*., 2006) explains the reason of financial pressures that drive the wireless communication network future towards auto-configuration. An additional key feature of Femtocell technology is that there no new user equipment (UE) (Chowdhury, M. Z., *et al*., 2013). The same UE can be used under Macrocell coverage and roam in Femtocell's territory. This indeed strengthen the point of cost saving and further more Femtocell do not require dual-mode handset (in contrast with 3G/WiFi unlicensed Mobile Access (UMA) technology (Mobile Experts). In view of the Femtocell significant deployment in cellular technology, LTE that is using Orthogonal Frequency Domain Multiple Access (OFDMA) and IP-based provides a brand new platform to accommodate Femtocell (Femtocell backhaul is intrinsically IP). (Mobile Experts) claimed that 70 million small cells will be shipped in year 2017 (including Femtocell and Picocells). Moreover, that LTE small cell will occupy the major part of forecast growth in the next 5 years with more than two-thirds of small cells will be deployed in 2017(Mobile Experts). Although there are plenty of technical approaches in small cell technology, Femtocell is still the most attractive choice. Journal by (Mostafa, Z. C., et. al., 2010) highlighted that Femtocell services larger amount of indoor users when compared to Fixed Mobile Convergence (FMC).The paper is organized as follows. Related Works described previous published related works. Cross Channel Interference Modeling section introduces the system modeling and calculation of the metrics. Results and Analysis section evaluates the performance of the system and the paper is ended with conclusion.

RELATED WORKS

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A few published related works are done to analyze FFR techniques for interference mitigation in hybrid network (Claussen, H., 2007), (C. Bouras *et al.*, 2013), (Biblios, D, *et al.*, 2013), (Bouras, C., *et al.*, 2013). Research by (Claussen, H., 2007) introduced a power diversity control to manage constant Femtocell radius inUniversal Mobile Telecommunications System (UMTS) system. The power control method by (C. Bouras, *et al.*, 2013) has introduced three power control methods of fixed power scheme, constant radius scheme and target Signal to Interference Noise Ratio (SINR) scheme in hybrid LTE-A system. The introduction of probability density function (PDF) of SINR is also introduced by (Sung, K. W., et. al., 2010) to further evaluate system performance, contribute in radio resource management, and radio network planning. The novelty of this research is the integration and enhancement of the technique proposed by (Bilios, D., *et al.*, 2013) and (Bouras, C., *et al.*, 2013). Paper by (Bilios, D. *et al.*, 2013) introduced the dynamic frequency allocation using FFR method to optimize inner region radius and inner region resource allocation to reduce total interference. Research by (Bouras, C. *et al.*, 2013) incorporated Femtocell/Macrocell environment into FFR and optimized the system based on three metrics which are total throughput, Jain's Fairness Index and weighted Throughput. This proposed work has further analyzes the hybrid system by(Bouras, C., et. al. 2013) with more realistic network parameters where users' mobility is evaluated over a period of time. Adaptive inner region radius and resource allocation is re-evaluated in a short period of time in order to achieve high user satisfaction (US). Dynamic frequency scheme is used in Femtocell resource assignment.

CROSS CHANNEL INTERFERENCE MODELING

Interference is the common problem in the hybrid system. By considering only the downlink, Femtocell users are subjected to the cross channel interference from Macrocell base station or co-channel interference from neighboring Femtocell base station. While Macrocell users in a hybrid network will experience interference from Femtocell base station as depicted in Figure-1.

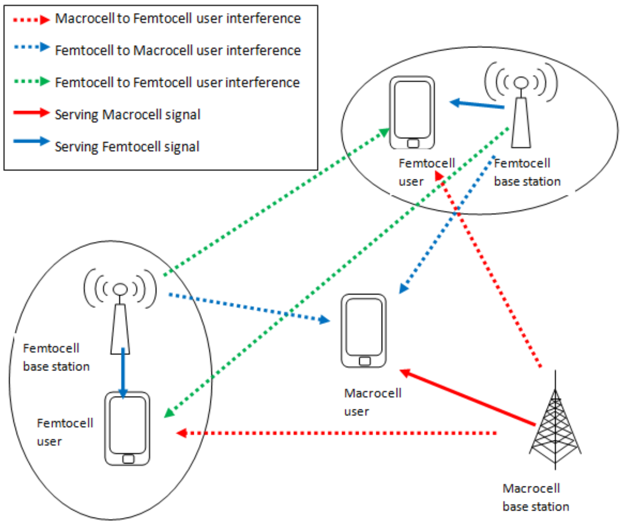

Figure-1. Downlink Interference in hybrid network.

In order to mitigate interference in a hybrid system, frequency allocation has to be controlled intelligently. Macro-users in the inner radius region are assigned as sub-band A.While in case Femtocell users attached to the Femtocells fall in inner radius region are assigned as sub-band B, C or D. The outer region of Macrocell users assigned sub-bands B, C or D, while Femtocells in this particular region are intelligently assigned unused subbands by Macrocell with either B, C or D. The specific frequency allocation scheme is summarized in Table-1. Such Femtocells frequency allocation is positioned approximately equal distance from each of the neighboring Macrocell center.

Table-1. Specific frequency allocation scheme.

	Macro-user	**Femtocell user**
Inner region	Subband A	Subband B, C, D
Outer region	Subband B, C, D	Subband A, B, C, D (as long as the subband is not used by the outer region)

The numerical involves in the simulation consists of Signal Interference to Noise Ratio (SINR), total throughput and user satisfaction (US). Research in (3GPP-TR 36.814 V9.0.0, 2010) indicates the path loss between Macrocell base station and Macro user (with operating frequency 2 GHz) is described in Equation (1):

$$PL_{MU}[dB] = 15.3 + 37.6\log_{10}(d[m]) + S^{out} \quad (1)$$

where,
d= Distance of Macrocell base station and Macro users.

S^{out}=Outdoor shadowing, characterized by Gaussian distribution with zero mean and standard deviation

Femtocellusers are assumed outdoor in the experiment. Thus path loss from Femtocell base station to Femtocellusers is defined by Equation (2):

$$PL_{FU}[dB] = 38.46 + 20\log_{10}(d[m]) \quad (2)$$

Research in (3GPP-R1-050507 2005) determined channel gain as Equation (3):

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$$G = 10^{-\frac{PL}{10}} \quad (3)$$

When evaluating SINR downlink of a Macrouser, the impact of an adjacent Macrocells and Femtocells are taken into account. By considering m (Macrouser) on n (subcarrier) interfered by neighboring M (Macrocell neighbor) and F (neighboring Femtocell), the SINR defined in (3GPP-R1-050507, 2005) as:

$$SINR_{m,n} = \frac{G_{M,m,n} \cdot P_{M,n}}{\sigma_n^2 + \sum_{neigM} G_{m,neigM,n} \cdot P_{neighM,n} + \sum_F G_{m,F,n} \cdot P_{F,n}} \quad (4)$$

where,

$P_{X,n}$=Transmit power from serving/neighboring base station (Macrocell, Femtocell) on subcarrier n.
$G_{x,X,n}$=Channel gain of user x and serving cell X
σ_n^2=Power of Additive White Gaussian Noise (AWGN)

Downlink SINR of f (Femtouser) on n (subcarrier) interfered by neighboring F (Femtocells neighbor) and co-channel Macrocells is defined as:

$$SINR_{f,n} = \frac{G_{F,f,n} \cdot P_{F,n}}{\sigma_n^2 + \sum_{neigF} G_{f,neigF,n} \cdot P_{neighF,n} + \sum_M G_{f,M,n} \cdot P_{M,n}} \quad (5)$$

With the SINR value, the capacity available for a user x on subcarrier n is found by (Lei, H., et. al. 2007) is:

$$C_{x,n} = \Delta f \cdot \log_2(1 + \alpha SINR_{x,n}) \quad (6)$$

where, Δf = Subcarrier spacing
α = Constant in terms of bit error rate (BER) = -1.5/ln(5BER)

(Lee, P., *et al.* 2010) describes the total throughput of a Macrocell as:

$$T_M = \sum_m \sum_n \beta_{m,n} \cdot C_{m,n} \quad (7)$$

where,
$\beta_{m,n}$= Subcarrier available to Macrouser m, $\beta_{m,n}$=1 when subcarrier is assigned, $\beta_{m,n}$=0 when not assigned.

The metric that evaluate user's fairness, User Satisfaction (US) is defined as sum of the users' throughput divided by product of the maximum user's throughput and total number of users X in the cell.

$$US = \frac{\sum_{x=1}^{X} T_x}{max\_user\_throughput \cdot X} \quad (8)$$

Equation 8 describes US calculation of a network. When most of the users experience ultimate fairness, the US will indicates as 1. In the scenario of unfair, US will approach 0. In this research, US is an important metric that determine a healthy network behavior.

A summary of overall pseudo-code is as Figure-2. The algorithm considers every possible inner radius from 0 to R, where R is the radius of the Macrocell. The inner loop scans all possible spectrum partition from 0 Hz to channel bandwidth 5MHz with frequency step of 180 kHz (5 MHz has maximum number of 25 resource blocks, each having 180 kHz bandwidth). The evaluation is done through plotting total throughput and US versus inner region radius and inner region spectrum. The challenge part in the pseudocode is to evaluate the SINR value. The serving cell is decided by the users' locations. Users are randomly distributed in Macrocell inner region, outer region or under Femtocell's coverage. Interference of each user's locations is evaluated by considering the contribution of each co-channel neighbors (Macrocells and Femtocells). From mathematical point of view (equation 4, 5), the transmit power of serving and adjacent cells as well as channel gain contributed by serving and adjacent cells are critical parameters to identify the important metrics such as SINR, capacity, throughput and US.

```
Generate Macrocells;
GenerateFemtocells;
Generate users();
for r=0:stepR:R
%scan all the radius
for b=0:N
allocate_RBs();
%scan all the RBs according to Figure-2
for x=1:X
%for all users
    Calculate SINR(x);   %based on equation (1)
    Calculate capacity;   %based on equation (2)
    Calculatethrougput(x);%based on equation (3)
end
calculate_total_througput(r,b);
calculate_US(r,b);
end
end

Select optimal radius&rb_US();
Perform adaptation process();%periodically repeat
the procedure to optimize the performance base on
users' mobility
```

Figure-2. Pseudo-code.

RESULTS AND ANALYSIS

The proposed hybrid system could be considered novel. Such hybrid referred to the integration of Femtocell and fractional frequency reuse (FFR) of the Macrocell system.

Simulation parameters

The simulation is conducted by specifying a list of parameters as presented in Table-2. The proposed system considered for the 5 MHz bandwidth of LTE system with 25 resource blocks (RBs) with each RB consists of 12-15 kHz subcarriers. The environment of typical urban is setup with the operating base stations at 2

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GHz (Band 1). Cost 231 Hata Model which has the highest path loss in urban area is used by (Shabbir, N., 2011) and (Aragon-Zavala, A., 2008). In order to simulate the real world application, the Femtocells and users are uniformly distributed and randomly generated. The focal point of the topology is selected as it is surrounded by six s adjacent channels neighboring Macrocells as shown in Figure-3. To further investigate the practical use of Femtocell, each of the Femtocell consists of at least one simulated user. In the scenario under discussion, there are four Femtocells and 24 users.

Selection of optimal point for inner region radius and RB

The analysis is done to select the FFR scheme that maximizes US and throughput. Figure 4 and 5 show the optimum throughput correspondence user satisfaction verses inner region radius and inner region bandwidth allocation. Based on the Figure 4, the variation of the inner region radius from 0m (frequency reuse 3 model) to 250m helps to enhance the throughput up to 56.11 Mbps. While the inner radius increment has decreases the throughput.

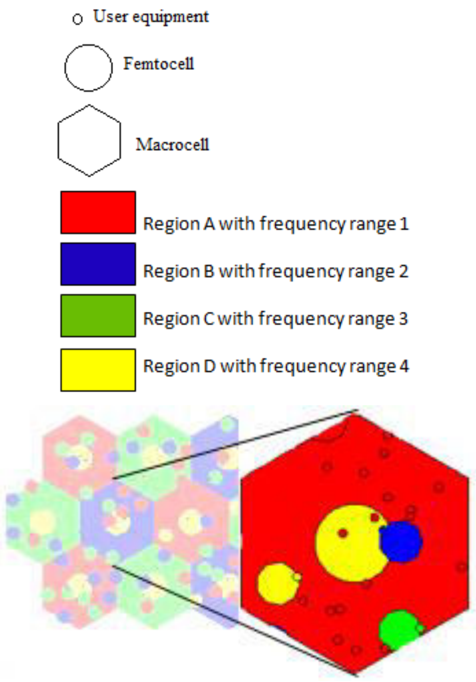

Figure-3. Users distribution.

Table-2. Simulation parameters.

Parameter	Units	Value
System bandwidth	**MHz**	**5**
Number of Resource blocks	RB	25
Carrier frequency	MHz	2000
Macrocell radius	m	250
Femtocell radius	m	41.67
Intersite Distance	m	500
Correlation distance	m	40
Channel model		3GPP Typical urban
User's speed	km/h	3, Pedestrian A
Path loss	dB	Cost 231 Hata Model
Macrocell BS Transmit power	W	20
Femtocell BS Transmit power	mW	20
Power noise density	dBm/Hz	-174
Total Macrocells		18
Total users		360
Total Femtocells		90

The user satisfaction achieves 0.07544 at the maximum throughput. The corresponding inner region radius is in the range of 33.3 m to 66.75 m. Besides, the optimum throughput is achieved only if the bandwidth of the system is fully assigned to the inner region cells as shown in Figure-5. This satisfies only a small group of users, approximately 7.5% of total users. Nevertheless, the individual throughput is directly impacting the user experience. Importantly the user fairness is emphasized in this analysis.

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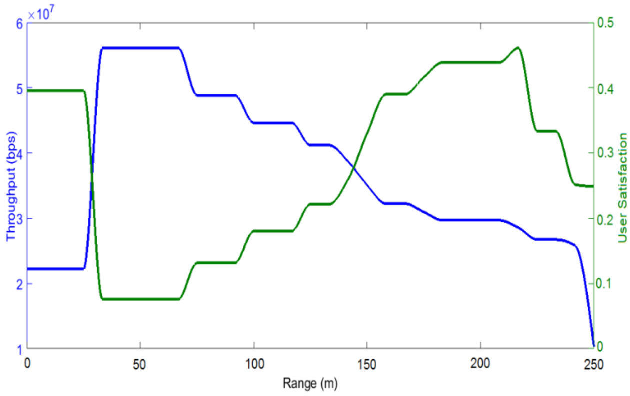


Figure-4. Total throughput and user satisfaction versus inner region radius plot at optimum throughput.

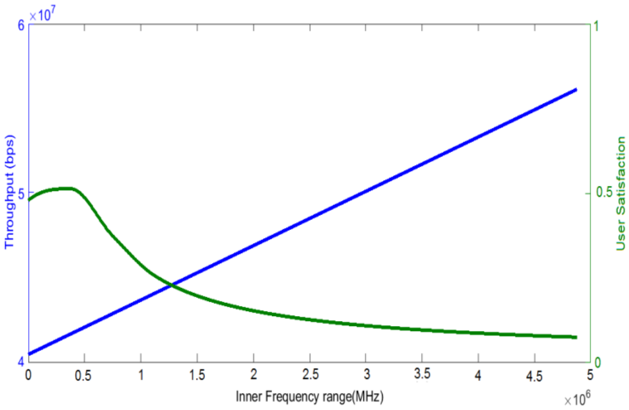


Figure-5. Total throughput and user satisfaction versus inner region bandwidth plot at optimum throughput.

Figure-6 and 7 highlighted the system performance when the user satisfaction is optimum. The user satisfaction of the system achieves highest ratio of 0.6368 when inner region radius is in the range of 125 m to 133.4 m. The price of having high US is compensated by having the throughput of 37.78 Mbps. The optimized inner radius bandwidth falls at 1.5 MHz where further increase of inner region resource draws to the decreasing of US. Generally, the system US is optimized when the system is allocating 1.5 MHz bandwidth to the inner region.

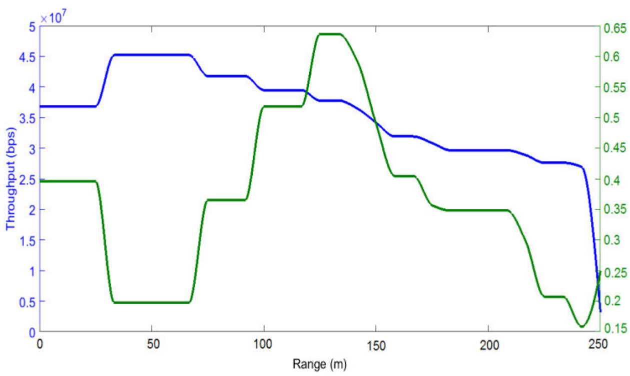


Figure-6. Total throughput and user satisfaction versus inner region radius plot at optimum user fairness.

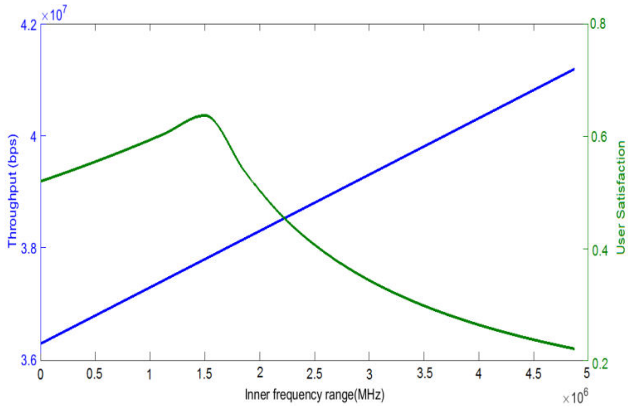
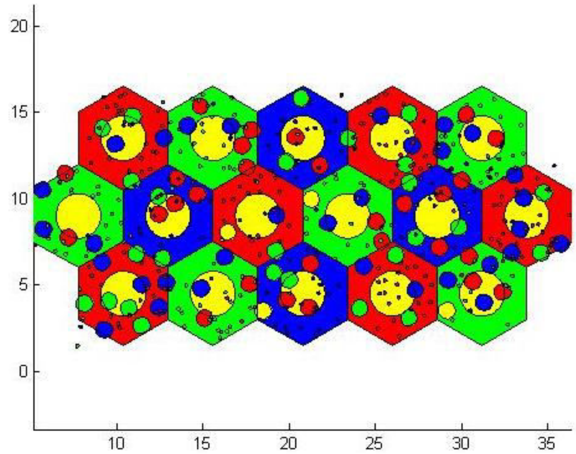


Figure-7. Total throughput and user satisfaction versus inner region bandwidth plot at optimum user satisfaction.

Intelligent FFR scheme

The scheme is further enhanced by simulating the real world situation where moving users is taken into consideration. The initial users' distribution is displayed in Figure-3. After moving randomly in the speed of 3 km/h (Pedestrian A channel model (3GPP-TS 25.890 2002)) and 124.7s (total time calculated based on average distance for the users to move with 3 km/h and in a distance not more than the radius of Macrocell), the final location of the users is as shown in Figure-8. A lower speed of 3 km/h is chosen to simplify the pseudo-code. While user moves at higher speed, additional factors need to be considered such as frequent handover between based stations may causes drop of system performance (this is not under the discussion in this paper).



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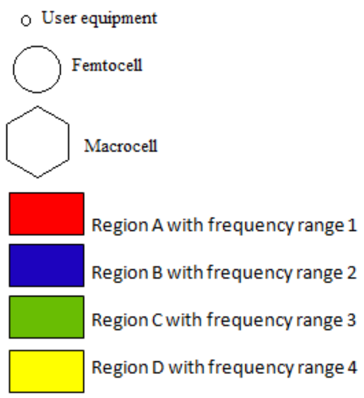

Figure-8. Topology of optimal FFR scheme after 128.7s.

As the users move around randomly, the intelligent scheme adjust the bandwidth allocation and radius of the inner region to ensure the resource fairness or high throughput obtained by all users. Figure-9 shows the comparison of the non-adaptive scheme and intelligent scheme of both optimum throughput and optimum user satisfaction based system. The constant plot of subcarrier allocation for the case of non-adaptive scheme is illustrated in the graph at the top in Figure-9. At 12.47s, the optimal user satisfaction based system starts to adjust the inner region resource allocation due to randommobility users. Optimal throughput based system regulates the resource allocation after 37.42s in order to achieve high total throughput. In order to optimize the system in terms of user satisfaction or high throughput, inner region radius is intelligently modified from the beginning of the experiment. For non-adaptive scenario, constant inner region radius is observed.

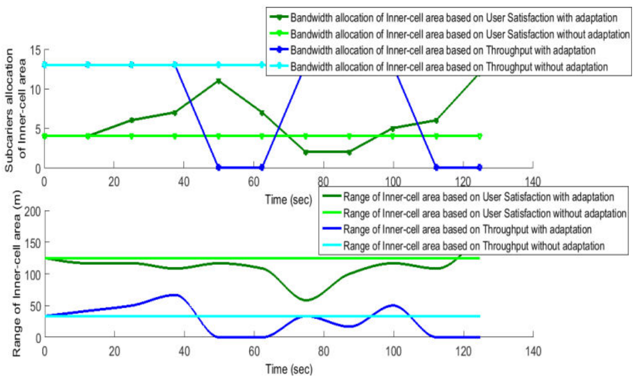

Figure-9. Inner region subcarrier allocation and radius adjustment over time for adaptive and non-adaptive scheme.

The effectiveness of the intelligent scheme is reflected in Figure-10. The intelligent control drives the user satisfaction as high as possible with less fluctuation. Comparatively, the US without adaptation fluctuates more drastically and having lower US values when compared to USwith adaptation as overall. The fluctuation reflects the user mobility across time. Approximately at 13s experiment starts, the adaptation system controls the inner region radius and resource allocation. Right after 13s, US without adaptation shows the sign of dropping while US with adaptation gives higher and stable US values. The total throughput plot does not achieve the highest value when it is plotted across time. This is expected as the system is trying to distribute the resource (bandwidth usage) fairly among the users.

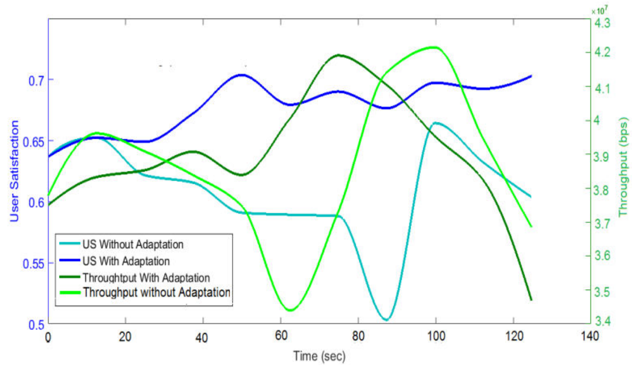

Figure-10. US and total throughput with and without adaptation plot across time.

CONCLUSIONS

In this paper, the FFR is introduced into a hybrid system which consists of Macrocells and Femtocells. The user fairness optimal point of inner region radius and inner region resource allocation is obtained and dynamically controlled base on the users' movement. Over a period of 124s, the system successfully shows that the US can be controlled and maintained at high level with US approximately 10% improvement at 124s. A possible future work can be extended to have evaluation on preplanned Femtocells in the network. In the scenario of excessive resources, Femtocells can be used to boost up the system performance. The number of Femtocells will optimize the throughput or the user fairness in the network that eventually could improve the quality of services (QoS).

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