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Improving LTE- A Indoor Capacity using Indoor Relay

Balume mugaruka[1]
Department of Electrical Engineering
Pan African University, Institute for Basic Sciences, Technology and Innovation (PAUSTI), Kenya

P.K Langat [2]
Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya

Jaafar A. Aldhaibani [3]
The University of Information Technology and Communication (UOITC), Iraq

A. yahya[4]
Botswana International University of Science and Technology (BIUST), Botswana

ABSTRACT

LTE- Advanced is essential to provide high transmission capacity and broad coverage network from the distance near to the base station up to the cell edge and also to shadow areas such as indoor environments. Due to the indoor penetration loss, the signal from the outdoor base station reaches the indoor users with low strength leading to low signal plus interferences and noise ratio (SINR), hence providing low capacity. This paper provides a way of improving indoor capacity using an outdoor base station of one antenna, indoor relay with one receiving directional antenna and one transmitting Omnidirectional antenna, with an indoor user with one Omni directional antenna. The impact of deploying the indoor relay to enhance the indoor users' capacity is shown by great performance when the indoor relay is connected to the indoor relay instead of the outdoor base station. The numerical values of capacity for indoor users at different locations show +80% capacity improvement at the handover point, the capacity at 250 m is improved from 1.4bit/s/Hz to the maximum capacity (7bits/s/Hz). Also, an improvement of

+60% is seen at distance from 25m to 50m for both sides of the relay location. Finally, this paper tacks on account the power balance algorithm to reduce the power consumption and giving more space to the outdoor at the cell edge.

Keywords: LTE-A, indoor capacity, Relaying, Relay location, Saturation capacity

I. INTRODUCTION

The demand of high capacity and broad coverage for indoor users has dramatically increased in recent years and will keep increasing due to newly developed applications such as social media applications, need of data in business building such as banks, mall, offices and hospitals and public transport[1]. To overcome this problem indoor relaying is a promising technique in which relay is placed indoor where the capacity and coverage needed to be increased as it has been used to improve capacity for outdoor cell edge and reducing the power transmitted from the base station[2]. The concept of deploying a relay is similar to that of a repeater but the relay is able to process the received signal from the outdoor base station before it forwards it to the users. From the cost part of the network, a relay reduces the cost of network implementation by reducing the number of base stations in a given area and reduces also the inter-cell interferences [3]. The relay is devised into two main categories:

Amplify and forward relay (AF) this type of relay only amplifies and then forwards the received signal from a base station to the users in town link or the signal received for users to the base station in the uplink. Its advantage is that it introduces no delay in the network but has the disadvantage of reducing the performance of the overall network as it also amplifies noise and interferences [4].

Decode and forward relay (DF) This type of relay not only amplifies the received from the base station to use and from use to base station, it also processes it (encode, decode, modulate and demodulate the signal before retransmission) [5]. Its advantage is that it removes the noise and interferences of the received signal, hence improving the performance. For this paper decode and forward is used as the performance of the overall network matters than transmission time.

II. INDOOR CAPACITY DEGRADATION

Application with higher bandwidth, are most likely run on indoor device[6]. In order to carry this traffic by mobile networks, the outdoor base station has to penetrate outdoor walls and windows to serve the indoor users. The penetration loss depends on the type of materials of the building. Different materials and their penetration losses are shown in table1[7], [8]

Materials	Penetration
Single concrete	20dB
Glass	15dB
wood	5dB
Ceramic tile wall	12dB
Concrete block	15dB
Metals	25dB

Table 1. Indoor penetration loses

III. SYSTEM MODELING

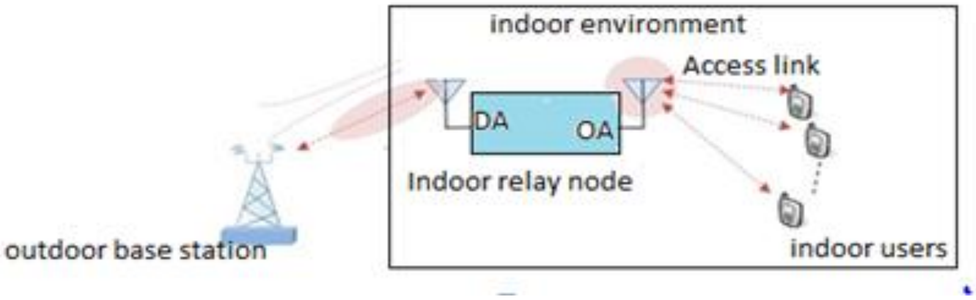

Fig. 1 proposed an indoor relaying network

As it is seen from **Fig 1**, the system has an outdoor base station, an indoor base station with a directional antenna with the receiving side and the omnidirectional antenna at the side where it is attached to the users

In an indoor relaying communication of figure 1 an outdoor base station transmits to the indoor relay in the first step, the relay receives the signal and noise from the base station, decodes and amplifies it then retransmits it to the users attached to it in the second steps of communication [1]. The piecework of this paper is divided into too many steps: the first analyze the capacity of indoor users without a relay while the second analyzes when indoor users are connected to an indoor relay.

3.1 Capacity without a Relay

In traditional mobile communication, a signal is transmitted from the outdoor base station to the indoor users[9]. For this case the capacity of the indoor users is affected not only by the distance, path loss, and fading, but also and most important by the indoor penetration losses and loss due to indoor objects such as tables, beds, etc. for this paper we only consider the penetration loss due to construction materials as the losses due to indoor objects is very small and negligible[10]. In wireless communication, the capacity depends on the transmitted power, received power, signal plus interference and noise ration and the bandwidth of the channel and the path loss[1].

The received signal at a given user in the cell from the base station and considering one interference cell [1].

$$\boldsymbol{R_{x,k}} = \sqrt{\boldsymbol{P_c}} \times \boldsymbol{H_{c,k}} \times \boldsymbol{X_{c,k}} + \left(\sum_{j=0}^{N} \sqrt{\boldsymbol{P_j}} \times \boldsymbol{H_{j,k}} \times \boldsymbol{X_{j,k}}\right) + \boldsymbol{W_{pl}} + \boldsymbol{I_L} \tag{1}$$

Where $R_{x,k}$ is the received signal at k user, P_C is the power from the main base station, P_j is the power from the interference base station , $H_{c,k}$ *and* $H_{j,k}$ are the fading channel gain from the main base station and the interference base station, $X_{c,k}$ and $X_{j,k}$ are the transmitted signals from the main and the interference base station, W_{pl} is the wall penetration loos has a value of 20dB for urban area ,15dB for suburban and 0dB for rural area[11].I_L Is the indoor loss and it can be neglected due to its small value.

The signal plus interference and noise ration being depend on the received signal for k user at a distance D_i from the central base station and at $d_i^{-\alpha}$ from the interference base station, is given by equation (2)

$$\boldsymbol{\rho_{c,k}} = \frac{\mathbf{P_c \times (H_{c,k})^2 - (W_{out_l} + I_L + W_{in_l} + N_k)}}{\mathbf{N_k + \sum_{j=0}^{N} \sqrt{P_j} \times (H_{j,k})^2 - W_{out_l} + I_L + W_{in_l}}} \tag{2}$$

With $D_i^{-\alpha}$ and $d_i^{-\alpha}$ the user distance from the main base station and the interference base stion respectively, N_p the noise power due to the channel.

For the traditional network, the capacity of a given cell is divided into the maximum capacity and average capacity as shown in the equation.

$$\mathbf{C} = \begin{Bmatrix} \boldsymbol{C_{max}}\ \mathbf{0} < \boldsymbol{D_i} \le \boldsymbol{X_s} \\ \mathbf{log_2(1 + \rho_{c,k})} \boldsymbol{X_s} < \boldsymbol{D_i} < \boldsymbol{R} \end{Bmatrix} \tag{3}$$

Subsisting the signal plus interference and noise ratio (SINR), $\rho_i$by its value ginen in equation (2) the capacity without a relay is

$$\boldsymbol{C_i} = \begin{cases} \boldsymbol{c_{max}}, & \mathbf{0} < \boldsymbol{D_i} < \boldsymbol{X_s} \\ \mathbf{log_2}\left(\mathbf{1} + \left(\frac{\left((\boldsymbol{P_c} \times \boldsymbol{D_i^{-\alpha}}) - (\mathbf{W_{out_l} + I_L + W_{in_l} + N_k})\right)}{\left((\boldsymbol{P_j} \times \boldsymbol{d_i^{-\alpha}}) + (\mathbf{W_{out_l} + I_L + W_{in_l}} + \boldsymbol{N_P})\right)}\right)\right), & \boldsymbol{X_s} < \boldsymbol{D_i} < \boldsymbol{R} \end{cases} \tag{4}$$

Where C is the capacity at a given point in the cell, C_{max} is the maximum capacity given by the hard spectrum efficiently, ρ_i is the SINR at the particular location in cellthe .D_i , X_s, R are the distance of the user , the cell saturation distance and x_s

3.2 Handover Location

Handover is a process of changing the serving cell to another without losing the connectivity due to user mobility between the cell due to low signal strength or to congestion[12]. In relaying networks, the handover is more complicated due to the density of the cell and to a big difference of macro cell and relay cell power[3]. For this reason, there is a need for appropriate methods to deal with the handover in relaying networks. Is this paper power balanced algorithm (PBA), based on better signal plus interference and noise ratio of the different nodes as shown in Figure2.

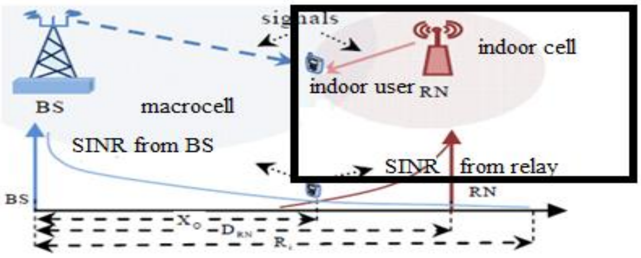

Fig. 2 Handover decision

3.3 Capacity with a Relay

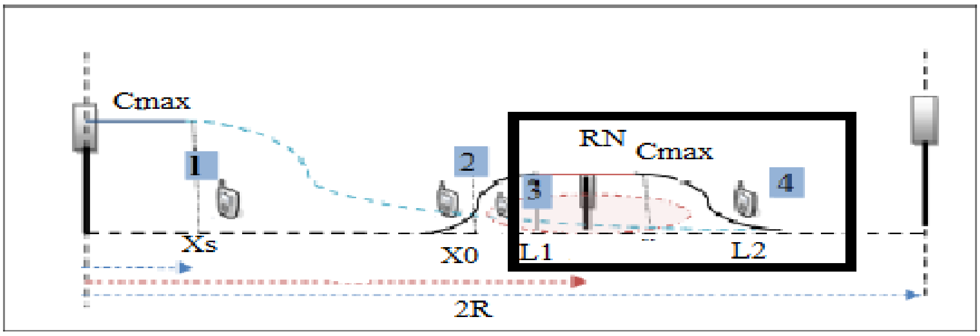

Fig. 3 Proposed indoor relaying

From (2), it is seen that the capacity of users decreases when the users are inside the building due to the walls penetration loss. For this reason, a relay is placed inside a building to cover the indoor users as seen in **fig 5**. The received signals at location L1 for user 3 and at location L2 for user 4 are respectively given by (5) and (6).

$$R_{L1} = \sqrt{P_{RN}} \times H_{RNL1} \times X_{RNL1} + \sqrt{P_C} \times H_c + W_{pl} \quad (5)$$

$$R_{L2} = \sqrt{P_{RN}} \times H_{RNL2} \times X_{RNL2} + \sqrt{P_c} \times H_c + W_{pl} \quad (6)$$

Where P_{RN} is the relay power, H_{RNL1} is the fading channel for usre at location L_1, H_{RNL2} is the fading channel for user at location L_2.

From these two equations, the signal plus interference plus noise ratio at each location can be calculated

$$\boldsymbol{\rho_{L1}}=\left(\frac{\left(\left(P_{RN(L2-DRN)}{}^{-\alpha}\right)-W_{pl}\right)}{\left(P_c\times L_1{}^{-\alpha}+N_p\right)}\right) \tag{7}$$

$$\boldsymbol{\rho_{L2}}=\left(\frac{\left(\left(P_{RN(L2-DRN)}{}^{-\alpha}\right)-W_{pl}\right)}{\left(P_c\times L_2{}^{-\alpha}+N_p\right)}\right) \tag{8}$$

From SINR of equation (7) and (8), the capacity at each location is calculated using Shannon theorem [1]

$$C_{L_1}=\begin{cases}\log_2\left(1+\rho_{L_1}\right) & x_0<D_i<L_1\\ C_{max} & L_1<D_i<D_{RN}\end{cases} \tag{9}$$

$$C_{L_2}=\begin{cases}\log_2\left(1+\rho_{L_2}\right) & D_{RN}<D_i<L_2\\ C_{max} & L_2<D_i<R\end{cases} \tag{10}$$

Substituting the signal plus interference and noise ratio at each location by the values given respectively in (6) and (7), the capacity is now given by

$$C_{L1}\begin{cases}C_{max}\,, & L_1<D_i<D_{RN}\\ \log_2\left(1+\left(\frac{\left((P_{RN}(D_{RN}-L_1)^{-\alpha})-W_{pl}\right)}{\left((P_c\times L_2{}^{-\alpha})+W_{pl}+N_p\right)}\right)\right), & X_0<D_i<L_1\end{cases} \tag{11}$$

$$C_{L2}=\begin{cases}C_{max}, & D_{RN}<D_i<L_2\\ \log_2\left(1+\left(\frac{\left((P_{RN}(L_2-D_{RN})^{-\alpha})-W_{pl}\right)}{\left((P_c\times L_2{}^{-\alpha})+W_{pl}+N_p\right)}\right)\right), & L_2<D_i<R\end{cases} \tag{12}$$

Where $\boldsymbol{P_{RN}}$ ***is*** the transmitted power of the indoor relay is, $\boldsymbol{D_{RN}}$ is the distance of the relay from the base station and $\boldsymbol{\alpha}$ is the path loss exponent.

IV. RESULTS AND DISCUSSION

The objective of this paper is to improve the indoor capacity by placing low power node known as relay node inside the building where the capacity is needed. To confirm the result indoor capacity without and with a relay are simulated, then the capacity is compared at different locations. Also to show the impact of indoor penetration loss, the outdoor scenario is compared to the indoor one. The simulation parameters are given in table

System		Base Station		Relay		User	
Parameter	Value	Parameter	Value		Value	Parameter	Value
Operating Frequency	2ghz	Height	25m	Height	2m	Height	1.7m
Noise Spectrum	-174db	Antenna Gain	14dbi	Antenna Gain	5dbi	Antenna Gain	0dbi
Path Loss	3	Antenna Type	O.D	Antenna Type	O.D, D.A	Antenna Type	O.D
Band Width	20ghz	Transmitting Power	0db	Transmitting Power	-20db	Power	.
Traffic Type	Full Duplex	Noise Figure	14dbi	Noise Figure	7db	Noise Figure	7db

Table 2 Simulation parameters

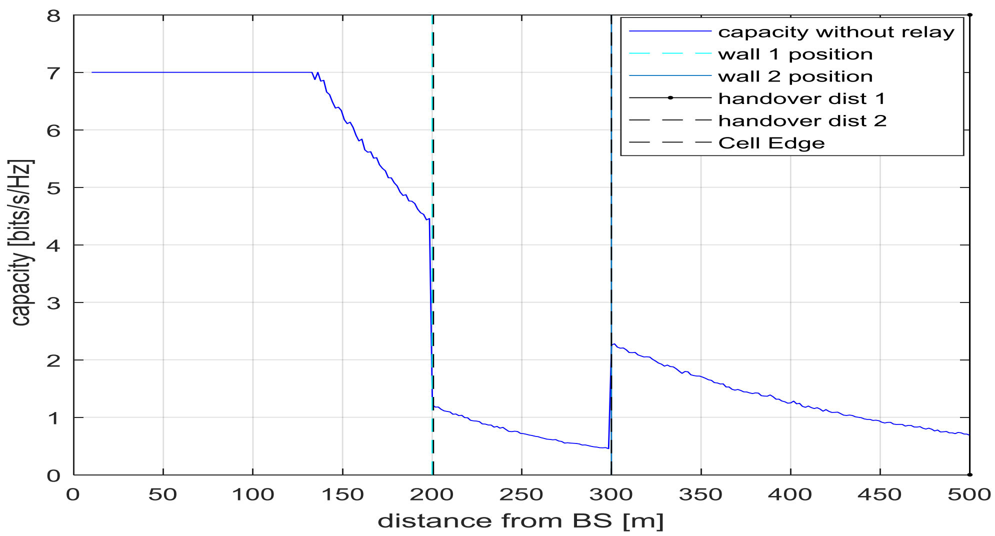

Fig. 4 Indoor capacity without a relay

Distance [m]	Capacity [bit/s]
Column1	Column2
199	4.71
201	2.71
210	1.99
220	1.8
230	1.72
240	1.51
250	1.4
260	1.39
270	1.19
280	1.11
290	1
300	0.95
301	2.16

Table 3 Indoor capacity without relay numerical results

Fig 4, shows the impact of the outdoor wall and indoor losses on the signal when the indoor users are connected to the outdoor base station. As is seen in the same figure, the capacity decreases considerably after passing wall one position. This is due to the outdoor wall penetration loss. Due to the distance from the cell and indoor losses, the capacity keeps decreasing up 0.95bit/s/Hz. Figure 4 proves that the indoor capacity is a victim of the wall and indoor losses, hence a need to find a solution.

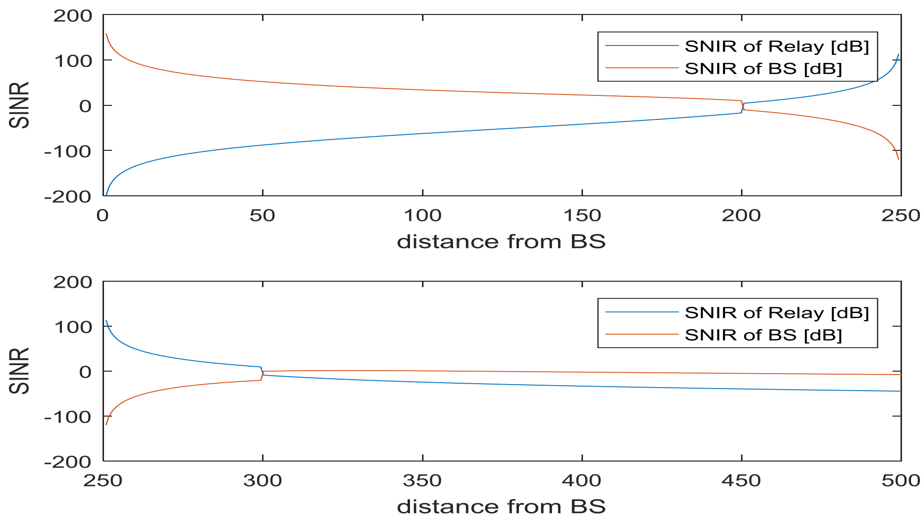

Fig. 5 Handover decision based on power balanced algorithm

fig 5 explains handover in relay network based on power balanced algorithm (PBA), which helps the user to handover from the station having worst signal plus interference and noise ratio (SINR) to the one with better SINR. This allows the indoor users to stay connected to the indoor relay; hence improving their performance and also off-loading the outdoor base station as it only takes care of the outdoor users, hence improving the cell edge capacity.

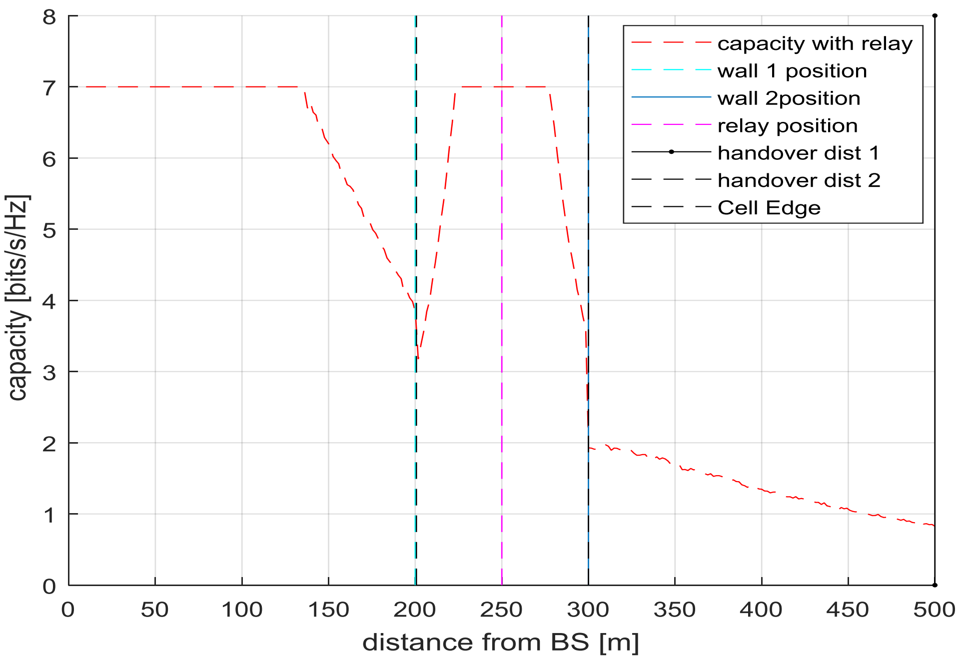

Fig. 6 Indoor capacity with relay numerical values

Distance [m]	Capacity [bit/s]
Column1	**Column2**
199	4.71
201	2.71
210	3.88
220	5.5
230	max
240	max
250	max
260	max
270	max
280	6.5
290	4.25
300	3.56
301	2.16

Table 4. Indoor capacity with relay numerical values

From **fig 6** it is seen that the outdoor capacity still the same on figure 4 but the indoor capacity has been improved due to the deployment of a relay at the center of the building. It also is seen that at 20 meters from the relay position for both sides we have the saturation capacity or the capacity is improved up to 95% due to the fact that users are closed to the relay station.

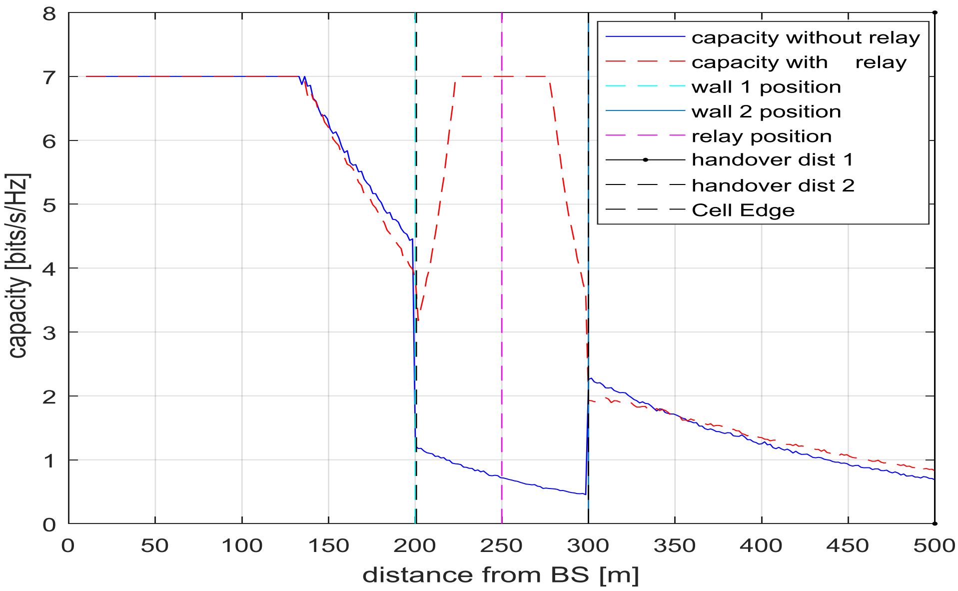

Fig. 7 Performance of indoor capacity with relay over indoor capacity without relay

Distance[m]	Capacity without relay[bit/s]	capacity wit relay[bit/s]
199	4.71	4.71
201	2.71	2.41
210	1.99	3.88
220	1.8	5.5
230	1.72	max
240	1.51	max
250	1.4	max
260	1.39	max
270	1.19	max
280	1.11	6.5
290	1	4.2
300	0.95	3.5
301	2.16	2.1

Table 5 Numerical results with and without a relay

Fig 7 shows the improvement of the indoor capacity when the indoor users are connected to the indoor relay instead of the outdoor base station. From table 4 it is seen that the capacity with relay is improved from 1.99 to 3.88 at 220 meters, from

1.72bit/s /Hz to maximum (7bits/s/Hz) from 220m to 250m and from 1.19 bit/s/Hz to max from 250m to 270meters, and then start decreasing with indoor distance and indoor losses up to 3.56bits/s/Hz. Also, there is 10% improvement at the cell edge due to the off-loading of macrocell by connected all the indoor users to the relay.

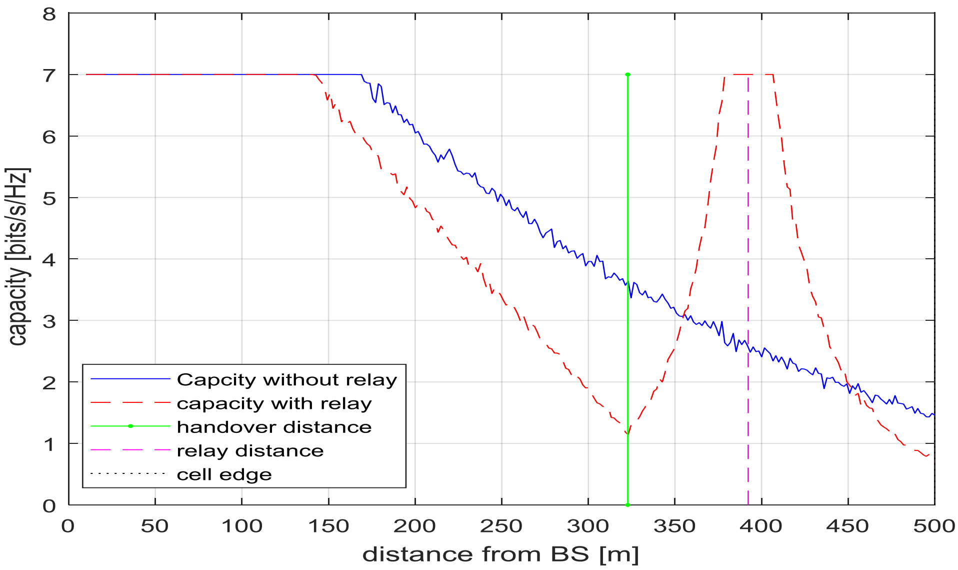

Fig. 8 Outdoor capacity with and with relay

Fig 8 shows that the outdoor capacity without and with a relay is better compared to the indoor capacity. This validates the indoor capacity degradation due to outdoor and indoor walls as the outdoor capacity is only affected by the path loss.

Validation process

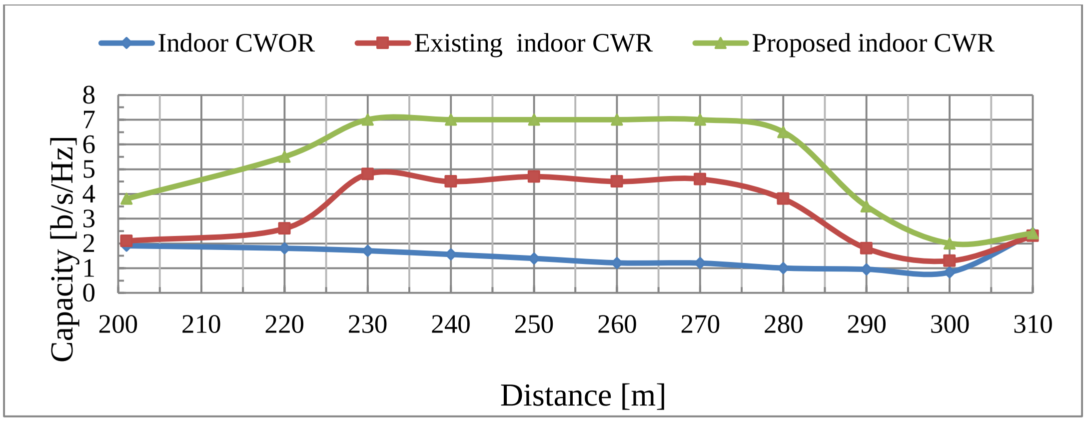

Fig. 9 Validation of results based on existing systems

The validation of the results is done by analyzing the indoor capacity degradation due to different building construction materials, whereby when the worst material is metal and can degrade indoor user capacity up 80% when the building is placed at the cell center and up to 95% at cell edge[8]. Then indoor capacity was improved up to 100% for indoor when the relay is deployed and also the cell edge capacity is improved by 15% due to the off-loading of the outdoor base station using power balance algorithm. Great performance in capacity is observed indoor compared [13]. In which a relay was deployed indoor for cell edge capacity improvement, and 38% improvement of the capacity was observed indoor while +60% was observed outdoor. For the coverage, 60% of coverage increased compared to femtocell[14]. This can only serve for a building of 40x 40 m and can only guaranty 60% of capacity improvement when deployed inside a building

V. CONCLUSION

The outdoor capacity performance is always better than the indoor capacity, due to the fact that apart from the distance loss dependent, outdoor wall penetration and indoor losses always affect the indoor capacity while the outdoor capacity is mainly affected only by the path loss distance. On the other hand, it is seen that for outdoor and indoor the capacity with relay is always better than the capacity without a relay, but more improvement when using a relay is seen indoor, this because the indoor users are closed to the relay and being placed indoor, the relay is less affected by the loss of the environment. Finally, the power balance algorithm shows much improvement in handover decision, as all the indoor users are only connected to the relay and when moving out they switch automatically to the outdoor base station, hence helps in off-loading the network to avoid congestion and improve the cell edge capacity.

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