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SMALL CELL NETWORK PLACEMENT MODELS FOR HETEROGENEOUS NETWORK DEPLOYMENTS IN SELECTED ENVIRONMENTS

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Abstract

An important evolution path for new-generation cellular networks specifically fifth generation networks (5G) is the projection of small cell base stations, these low power networks are primarily made up of femto, pico and micro cells. This proposition possesses the potentials to meet ever increasing network throughput needs due to augmented Base Station (BS) density.
Measurements were obtained of variations of received signal strength with distance from the field of small cell base stations represented by access points AP's configured to behave like Femto AP-cells in the unlicensed spectrum. These measurements were used to develop models that would enable optimal placement of cells depending on path loss in five selected environments. These models would be compared with existing path loss models to determine best fit for given scenarios.
It was found that majority of the models developed for the different environments had the free space path loss model as the most representative of path loss estimation even at close distances. The best environments for propagation included outdoor environments with little or no obstructions and small enclosed offices.

I. INTRODUCTION

Macro cells are prevailingly used to provide a widespread coverage area but few support high rate data services and this at relatively high transmission powers. One apparent approach is to make the existing cellular network power efficient and also to reduce the distance between nodes, hence reducing the transmission power. We can also improve network performance and service quality by offloading from these large macro-cells.
Spurred by increased demand for high throughput wireless services, cellular networks are evolving from traditional structures of high-power macro base stations (BSs) each with a large geographic area of coverage to smaller cell structures with low-power BSs such as micro, pico- and femto-BSs. Following from this increased BS density with shorter transmission distances, smaller cell networks are able to provide more uniform and higher data rates subscribers. This would result in a heterogeneous network structure comprising large macro-cells in combination with small cells offering increased bitrates per unit area [1].
5g networks are touted to deliver far greater rates of data to user's devices with incredibly high-speed connections. The network is advertised as essential for applications like autonomous vehicles to function. 5g networks requirements include smaller towers to be spread around cities more frequently than existing network generations, possibly every city block [2].
To provide ultra-high bandwidth in the 5G era, the coverage areas of mobile base stations will shrink. As a result, the number of base stations will greatly increase, with base station density expected to reach 10 times that of the 3G era [3].
From research it is observed that for large small cell populations of almost extreme heterogeneous situations, the macro - femto topology possesses the best performance in terms of energy efficiency followed by the macro-pico-femto configuration. The currently existing macro-macro system is the least, showing that the macro femto configuration EE improves as the number of femto-cells proliferate [4].
This creates the need to explore path loss interactions by developing placement models between cells in a co-channel spectrum deployment. If properly placed the problem of interference would be mitigated to a very low degree in the event of failure of Inter-cell Interference Co-ordination (ICIC) techniques due to extreme or relatively multiple proliferation of small cells of different types since literature has shown that throughput rises with BS density.

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II. MODEL DEVELOPMENT

The measurements were done in five environments namely: Open corridor, small offices with block walls and plaster board partitioning, large rooms with block walls and wooden doors, free or open space and free space with some measure of obstructions. These environments were selected because they represent the different environments in which small cells are likely to be deployed in conjunction with one another or with macro base stations. The environments are shown in Table 1:

Table 1 Measurement Sites

S/N	MEASUREMENT SITES
1	Open Corridor (Long hall way)
2	Free Space
3	Closed offices with block wall and plaster board partitioning
4	Large offices with block walls and wooden door partitions
5	Free Space with some obstructions

Two access Points AP's were used with SSID's Cell A Cell B with the following specifications in Table 2:

Table 2 Cell Specifications for Research

S/N	EQUIPMENT	SSID/CID	SPECIFICATIONS
A	Nano Station 2 Wireless Access Point	Cell A	10dBi X 2 Antenna gain Adaptive Polarity 20dBmTransmit power (Femto-cell) IEEE802.11b/g
B	TP-LINK wireless Router	Cell B	6dBi X 2 Antenna gain 20dBmTransmit power (Femto-cell) IEEE802.11b/g
C	Manufacturer Details N/A	32445/32449	10dBi Antenna gain 45dBm Transmit Power (Macro-cell) 2100MHz
C	Manufacturer Details N/A	32445/32449	10dBi Antenna gain 45dBm Transmit Power (Macro-cell) 2100MHz

Cell Placement Models

The RSSI's obtained for each site was taken using Wifiman© Software on a mobile phone representing the user equipment (UE) at selected spaced distances dependent on the Environment under consideration. The various models obtained from the plots of empirical data from site measurements of received signal strength and log of distance is presented in the various environments investigated. Received Signal Strength Indicator (RSSI) in dBm, x=distance in meters.

Table 3 Empirical models and validation Tables

S/N	Empirical Model	Cell	Environment	R-square (R_0)	Validation Result
1	*RSSI=-1.517310log10x-54.342*	A	Open Corridor	0.5563	Rejected
2	*RSSI=-2.251310log10x-22.389*	A	Free Space	0.8558	Accepted
3	*RSSI= -2.264810log10x-24.83*	B	Free Space	0.8584	Accepted
4	*RSSI=-1.333710log10x-23.561*	C	Free Space	0.9352	Accepted
5	*RSSI=-2.067610log10x-42.368*	B	Small Offices	0.7678	Accepted
6	*RSSI=-2.644610log10x-38.384*	A	Small Offices	0.9681	Accepted
7	*RSSI=-2.121210log10x-58.205*	A	Small offices (lateral)	0.7877	Accepted
8	*RSSI=-2.549310log10x-42.143*	A	Small Offices (Corridor)	0.8663	Accepted
9	*RSSI=-2.062410log10x-43.598*	A	Large Office	0.7602	Accepted
10	*RSSI=-2.383210log10x-16.378*	C	Free Space Slight Obstructions	0.9239	Accepted

Analysis of Models developed

To properly analyze the developed models we use the R-squared value on the basis that the closer it is to one (1) (we choose ≥ 0.7) we accept the model as valid and if ≤ 0.69 we reject the model. On the strength of that assumption the result validation column in Table 3 was developed and on that basis Model 1 in Table 3 is therefore rejected and others accepted.

Comparison of Models developed to existing models in Literature.

The accepted models were compared to existing literature to ascertain which of the existing models would be the best representation for real life implementation of cells.

Selected Models

Three major models were selected:

- Free Space Model
- The COST 231–Walfish–Ikegami model
- ITU indoor propagation model

Based on their characteristic properties the following models were matched to the following environments for validation and this result is presented in Table 4.

Table 4 Experimental Model vs. Selected Model per Cell Type

S/N	Model	Cell	Environment	Selected Model
2	*RSSI=-2.251310log10x-22.389*	A	Free Space	Free Space
3	*RSSI= -2.264810log10x-24.83*	B	Free Space	Free Space
4	*RSSI=-1.333710log10x-23.561*	C	Free Space	Free Space
5	*RSSI=-2.067610log10x-42.368*	B	Small Offices	ITU, Free Space
6	*RSSI=-2.644610log10x-38.384*	A	Small Offices	ITU, Free Space
7	*RSSI=-2.121210log10x-58.205*	A	Small Office Lateral	ITU ,Free Space
8	*RSSI=-2.549310log10x-42.143*	A	Corridor	ITU, Free Space
9	*RSSI=-2.062410log10x-43.598*	A	Large Office	ITU, Free Space
10	*RSSI=-2.383210log10x-16.378*	C	Urban	COST 231, Free Space

Model Validation

The theoretical models chosen in section were validated against the matched empirical models using the Root Mean Squared Error (RMSE). The Root Mean square Error (RMSE) is a standard measure of how much error exists between two sets of quantitative data. In most cases it compares a predicted value i.e. one data set and a known or observed value i.e. another data set. Generally the lower the RMSE, the lower the error. It is one of the most widely used statistic tools [5].

Mathematical representation:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(x-y)^2}{n}} \qquad (1)$$

Where x is a predicted value, y is the observed value and n is the number of observations.

Table 5 Model Comparisons based on RMSE

S/N	Model	Cell	Environment	Selected Model	RMSE (dBm)
2	*RSSI=-2.251310log10x-22.389*	A	Free Space	Free Space	12.829
3	*RSSI= -2.264810log10x-24.83*	B	Free Space	Free Space	10.61
4	*RSSI=-1.333710log10x-23.561*	C	Free Space	Free Space	7.2216
5	*RSSI=-2.067610log10x-42.368*	B	Small Offices	ITU, Free Space	7.661, 3.2245
6	*RSSI=-2.644610log10x-38.384*	A	Small Offices	ITU, Free Space	9.574, 7.48108
7	*RSSI=-2.121210log10x-58.205*	A	Small Office Lateral	ITU ,Free Space	12.124,9.67876
8	*RSSI=-2.549310log10x-42.143*	A	Corridor	ITU, Free Space	22.7688, 19.1031
9	*RSSI=-2.062410log10x-43.598*	A	Large Office	ITU, Free Space	8.3352,4.37838
10	*RSSI=-2.383210log10x-16.378*	C	Urban	COST 231, Free Space	38.5693,11.9678

Based on RMSE the Free Space models were chosen as best fits to the developed models for the selected environments as shown in Table 5.

The table below presents a summary of correction factors (cF) obtained from the RMSE between the Model RSSI's and actual RSSI for the adopted models. Going further:

∴Adopted Model RSSI =Actual RSSI + cF (dBm)

Table 6 Summary of correction factors for adopted model

Cell	Adopted Model	Correction Factor (*cF*) Based on RMSE (dBm)	Environment
A	Free Space	-12.829	Free space
B	Free Space	-10.61	Free space
C	Free Space	-7.221	Free space
B	Free Space	+3.2245	Small Office (LOS)
A	Free Space	+7.48108	Small Office (LOS)
A	Free Space	+19.1031	Small Office (Lateral)
A	Free Space	+9.67876	Corridor (LOS)
A	Free Space	+4.37838	Large Office (LOS)
C	Free Space	+11.9678	Free space (Obstructions)

Some of the Measurement Environments

Figure 1 Open Corridor (Long Hallway)

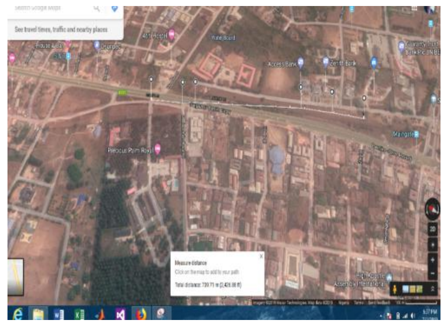

Figure 2 Free Space 2 (Satellite View)

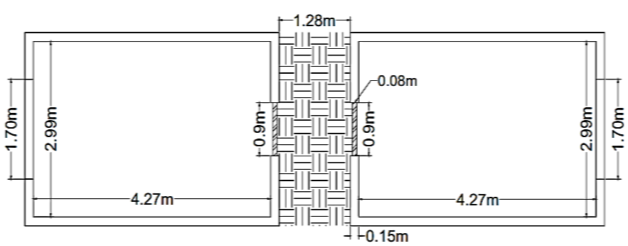

Figure 3 Small Office

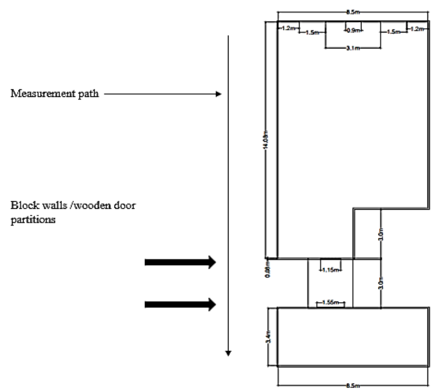

Figure 4 Large office

III. CONCLUSION

This research work aimed at obtaining empirical cell placement models for small cell (Femto) deployments based on RSSI. The models obtained showed lowest RMSE when compared against the free space model in three major environments: Free Space with no obstructions, Small Offices and Large Offices 7.2216, 3.2245, 4.37838 respectively with small offices being the lowest. Furthermore base stations with higher transmit powers had a lower RMSE and a smaller path-loss exponent than others in the same environments as the empirical models showed. The Free space model is the best model for path loss determination for small cells in the field. Correction factors were introduced to better fit the free space model to the empirical models. From the results presented as above, it can therefore be deduced that small cells perform better when in closer proximity to users in enclosed environments.

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