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Design of Web Based Software for Heterogeneous Network Deployment and Energy Efficiency Determination for Outdoor Cellular Communication Networks

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Abstract

In this paper a web-based software for modelling heterogeneous networks was developed in terms of coverage and efficiency for essentially outdoor areas. The networks referred to being cellular networks for commercial carriers in 4G and 5G technologies. A mathematical model of coverage of cellular networks in a hypothetical test bed scenario was obtained, taking into consideration network traffic density, transmitter gain, power. A Mathematical model was developed within the same test bed describing the energy efficiency of a heterogeneous network consisting of specific cell categories; femto, pico, and micro. Lastly a web-based information system was designed to enable estimation of number of cells for placement and associated network energy efficiency under different network deployment schemes using C# and the ASP.NET framework. Results indicate that the web-based system performs as per initial software specifications and is a veritable tool for quick and accurate planning of heterogeneous base station networks for network engineers for 4G and 5G networks. It was also found that multiple topology base station cooperation is more energy efficient than non- cooperative systems and the former always outperforms the latter in terms of Energy Efficiency and Quality of Service.

1. Introduction

In the past, communication network evolution was primarily hinged on spectral efficiency (SE) improvement. As technology has evolved, reduction in energy consumption has become almost as equally important. Also, the importance of the energy efficiency (EE) as a metric for network performance evaluation has grown [1]. The SE is the customary metric for measuring the efficiency of a communication system. It is a measure of how efficiently a resource (spectrum) is utilized. It in itself cannot quantify energy expenditure. Hence the introduction of a new metric: bits-per-Joule (bits/J). It can be defined as the maximum quantity of bits that can be delivered by the network per Joule consumed. Thus, it is simply the ratio of the capacity of a network to the rate of energy expended [2].

The global trend toward energy consumption reduction has led to the extension of the EE concept to devices with continuous power supply such as base stations (BS). Additionally, available spectral resources need to be efficiently utilized for transmission and this would naturally lead to a better quality of Service (QoS) for communication networks. In terms of digital connectivity, Internet users grew by 10% in 2016, this is up 354 million compared to 2015. Mobile social users also grew by 30% up 581 million in 2016 [3]. To nurture economic growth and improve communication technology; a low energy solution that will improve connectivity and meet mounting data demands has to be found [4].

Furthermore, in preparation to satisfy 5G requirements, mobile carriers must focus on 5G scenarios involving new technologies and solutions to upgrade and reconstruct existing microwave networks. Thus, network efficiency must be improved in order to get ready for the 5G era [5].

This paper attempts to solve these problems using a spatial domain approach rather than the regularly adopted frequency domain approach.

1.1 Related Works

[1] developed a tight closed-form approximation of the Energy Efficiency vs. Spectral Efficiency (EESE) trade-off for the uplink of a cellular communication system. They utilized closed form models developed to assess the EE performance of base station (BS) cooperation against non-cooperative system for both a theoretical power model and a realistic power model. They discovered that BS cooperation was far more energy efficient than non-cooperative systems. [6] investigated the accuracy of the Wyner Model for cellular networks. Their results showed that for the uplink, for both metrics (both uplink and downlink transmissions and both outage-based and average-based metrics).It was concluded that the Wyner model is in fact quite accurate for systems with a sufficient number of simultaneous users, e.g., a CDMA system. Conversely, it is broadly inaccurate otherwise. Turning to the downlink, the Wyner model becomes inaccurate even for systems with a large number of simultaneous users. This mars its use for real and practical networks of which some of these essential characteristics are lost. [7] used a random spatial model where BSs are modeled as a spatial Poisson point process (PPP). With the help of stochastic geometry, they showed the model to be tractable and of use in analyzing the outage probability and coverage in cellular networks. In the original model, it was assumed that each BS always had users to serve, and all the analyses focused on a typical user. At core the model only considers the spatial distribution of BSs, while the density and distribution of users are irrelevant. However, in a practical network, not all BSs are always active. Such effect becomes more prominent as the BS density increases. In this work the BSs and users were modeled as two independent PPPs. By doing so the user density effects can also be analyzed. [8] derived closed-form expressions of coverage performance for two-tier cellular networks based on stochastic geometry. Then the relationship between energy efficiency and the density of small-cells for the two-tier network was evaluated, the optimal density of small-cells that maximize energy efficiency under coverage performance constraints for the two-tier network was obtained.

2. Methodology

2.1 Developing the Network Energy Efficiency model

In this step the model describing the network energy efficiency was developed using the following model from literature where network energy efficiency (nEE) is given as: -

$$nEE = \frac{\text{Total Network Throughput}}{\text{Total Power Consumption in Network}} \quad [1] \qquad (1)$$

Following from the model developed, the best network topologies were obtained in terms of energy efficiency

Process:

Now we consider the scenario given by a two-tiered heterogeneous network under analysis. We denote the macro base station (MBS) throughput as TB having a total power consumption as PB.

For a small cell base station we define individual throughputs for each category of small cell micro, pico, femto as Tm, Tp, Tf, having individual power consumption as Pm, Pp, Pf.

Let us assume that the network consists of two base station types of macro and pico cells of one each, the network energy efficiency (nEE) becomes:

$$nEE = \frac{TB+Tp}{PB+Pp} \qquad (2)$$

Now if we increase the number of pico cells randomly to say 3, the energy efficiency becomes:

$$nEE = \frac{TB+Tp+Tp+Tp}{PB+Pp+Pp+Pp} \qquad (3)$$

Now adding another category of small cells say Femto and increase the number randomly the network energy efficiency becomes:

$$nEE = \frac{TB+Tp+Tp+Tp+Tf}{PB+Pp+Pp+Pp+Pf} \qquad (4)$$

Therefore, the network energy efficiency can be rewritten as: -

$$nEE = \frac{TB+3Tp+Tf}{PB+3Pp+Pf} \qquad (5)$$

If we have n_1, n_2, n_3 as the number of pico, femto, micro cells respectively, and incorporated within a single macro-base station then the network energy efficiency therefore becomes:-

$$nEE = \frac{TB+n_1Tp+n_2Tf+n_3m}{PB+n_1Pp+n_2Pf+n_3Pm} \qquad (6)$$

The models derived in equation (6) do not capture specific aspects of the network such as coverage area and quality of service.

If we introduce the concept of area, nEE can be rewritten as: -

$$\frac{TB+\lambda_p \pi R^2 T_p+\lambda_m \pi R^2 T_m+\lambda_f \pi R^2 T_f}{P_B+\lambda_p \pi R^2 P_P+\lambda_m \pi R^2 P_m+\lambda_f \pi R^2 P_f} \quad (7)$$

Where $\lambda b = \frac{n}{\pi R^2}$, λb is referred to as the base station density and πR^2 area under which n number of base stations i.e. n_1,n_2,n_3, exist, R= Radius of Coverage of macro base station.

2.2. Developing the Coverage Model

The coverage model is developed with the assumption that there is a uniform distribution of user equipment in the coverage area of interest, limited to the macro-cell coverage area. This model allows actual planning of the fully heterogeneous network based on gain and received signal strength related to macro base station traffic offloading and optimal small cell placement within the coverage region.

Following from models obtained from [9],

$$P_c = (Tr)P_t + P_f \quad (8)$$

This expresses the relationship between total power consumption of any base station where:

The equation establishes that total power consumption is dependent on traffic experienced by the mobile station (MS).

For the case of coverage of offloaded areas of the macro base station by small cells, we introduce the concept of surface area and directive gain.

It can be shown that when the angle in which the radiation is reduced, the directive gain goes up. As an example with an isotropic radiating source, the gain would be 0dB and the power density (Pd) at any given point would be the input power (Pin) divided by the surface area of the imaginary sphere at a distance R from the source. Hence gain

$$G = \frac{Power\ produced\ by\ antenna\ from\ far field\ source}{Power\ produced\ by\ a\ hypothetical\ lossless\ isotropic\ antenna} \quad (9)$$

Also it can be shown that:

Radiation angle $\Theta = G \times 360^0$

and gain in decibels is :

$GdB = 10X\log_{10}(G)$ (10a)

Let us assume we have *k* number of mobile stations per *A* square meters. Thus, the mean density can be given as:
$\lambda k = k$ per m2 (10b)
Now it can be shown that the coverage area of the various cell categories is as follows:

Femto cells = 4πRf2/*G* (11)

Pico cells = 4π *Rp2/G* (12)

Micro cells = 4π *Rm2/G* (13)

Macro cells $= 4\pi R_B^2/G$ (14)

Generally, cell coverage area = $4\pi r^2 G$, (15)

Another assumption in developing the traffic model is that the area covered by the base stations is spherical, it follows therefore that to find the number of cells to cover the area we need to divide the area under consideration by the coverage area of the small cell (also spherical) given by *a*. It would however be a close approximation.

Hence , $A = 4\pi R_B^2$ (16)

Hence number *n* of small cells required becomes:

$$n = \frac{Coverage\,Area\ of\ Macro\,Base\ Station}{Coverage\,Area\ of\ small\ cell\ base\ station} \quad (17)$$

Therefore $n = A/a$

A can also be expressed as area under interest to be covered by ***only*** small cells. For a squared area A becomes $Asq. = LxB$ and for a circular coverage area $Acirc. = \pi R^2$

We can therefore obtain the mean number of users expected in each cell type coverage area as: -

$Nu = \lambda k \ x\ 1/n$ (18)

To develop the coverage area model, we consider the modified traffic model from (8)

$P_c \le ((1 - Y)Tr)P_t + P_f$.

. It therefore follows that:

$$n = \frac{Y\ \text{x Area under consideration}}{Coverage\ area\ of\ small\ cell} \quad (19)$$

Therefore $n = \frac{Y\,X\,A}{a}$ (20)

Therefore the final traffic model becomes:

$$\boldsymbol{n} = \frac{\frac{Y}{m}A}{af} + \frac{\frac{Y}{m}A}{ap} + \frac{\frac{Y}{m}A}{am} \quad (21)$$

It can be inferred that therefore that the distance of small cell from BS becomes

$\chi = Rm * (1 - Y)$ (22)

assuming a relative free space outdoor environment and high interference probability, where *Rm =Radius of macro BS (m), and Y=% offloading of macro Bs by small cell*

It can be concluded that % offloading of macro BS by small cell cannot be more than 50% as this would make the BS less efficient and underutilized.

If there are different categories of small cells of area defined by *af, ap, am,* each having number of cells *nf, np, nm* respectively, then the assumption is that off-loading of the macro base station is shared among the various small cells.

Then the **total** number of small cells for specified coverage area and loading becomes:

$$n = nf + np + nm \tag{23}$$

2.3 Developing the software-based network analysis tool

The final models which were developed were used to design a software for network planning and analysis using C# in the Active Server Pages (ASP.Net) Framework, this for co-channel configurations and frequency reuse configurations. The Software model developed is a web-based information and resource system designed to run on any internet browser.

Web Applications are websites with dynamic content combined with server-side programming which provide functionalities such as user interfaces, connection to back-end databases, and generation of results to browsers [1]

Examples include: online banking systems, social networking sites, online shopping sites, online training, online forums, and blogs etc.

2.4 Software Requirements

Functional requirements*:* Functional requirements of the system are:

i. Plan heterogeneous network topology.
ii. Perform network energy efficiency assessment.
iii. View technical specifications of cells used in research.

Non-functional requirements: The application should be able to connect to the internet and it should be able to run on all internet browser platforms.

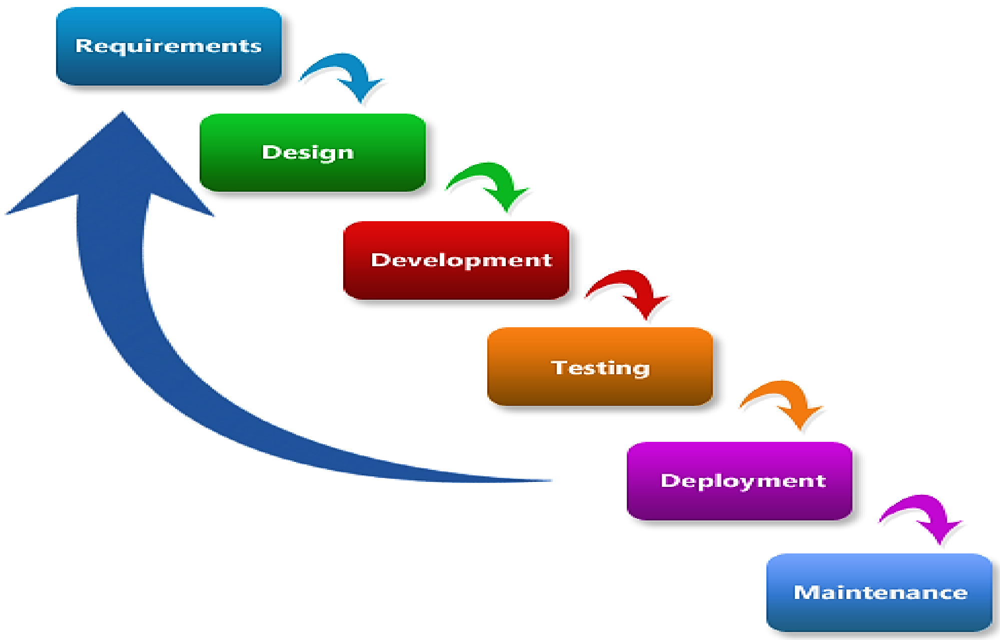

Figure 1 The Waterfall model

Requirements and specifications phase: The requirements of the system were first established and defined in detail to serve as system specifications.

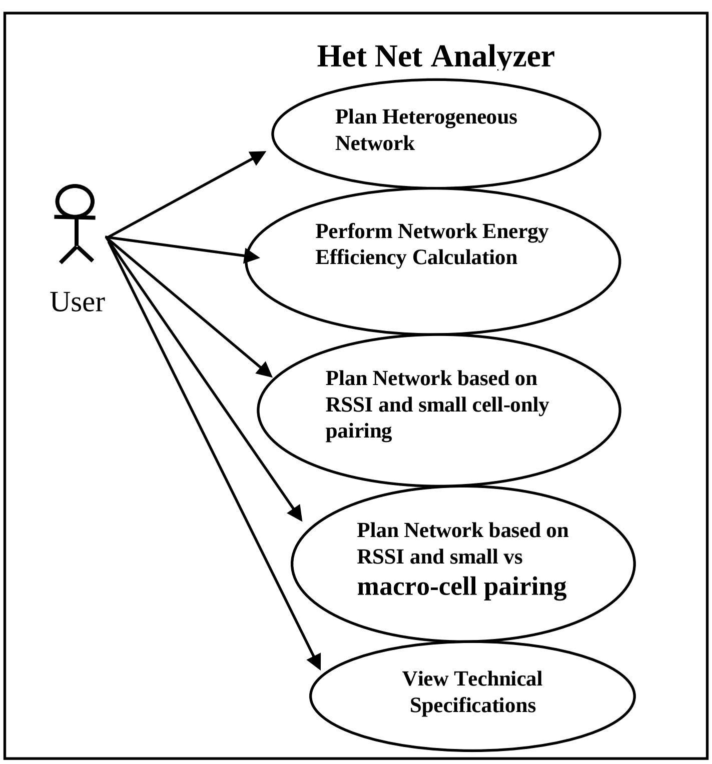

Figure 2 Use Case Diagram for Developed Application

2.4 System and Software Design

Here the system architecture was developed by defining system functions and relationships. The choice of which Software Development Life Cycle to use was made, the decision resting on the traditional "Waterfall "model due to the explicitness of the problem statement and as the model possesses good linearity and well-defined distinct stages.

3.Results and Discussion

3.1 Implementation and Unit Testing

Here the architectural model developed was implemented in code, using C# and the Visual Studio 2017 © Integrated Developer Environment specifically the ASP.NET Framework.

Figures 3 and 4 are screenshots of the developed web-based application showing a sample entry and in Figure 5 the results page

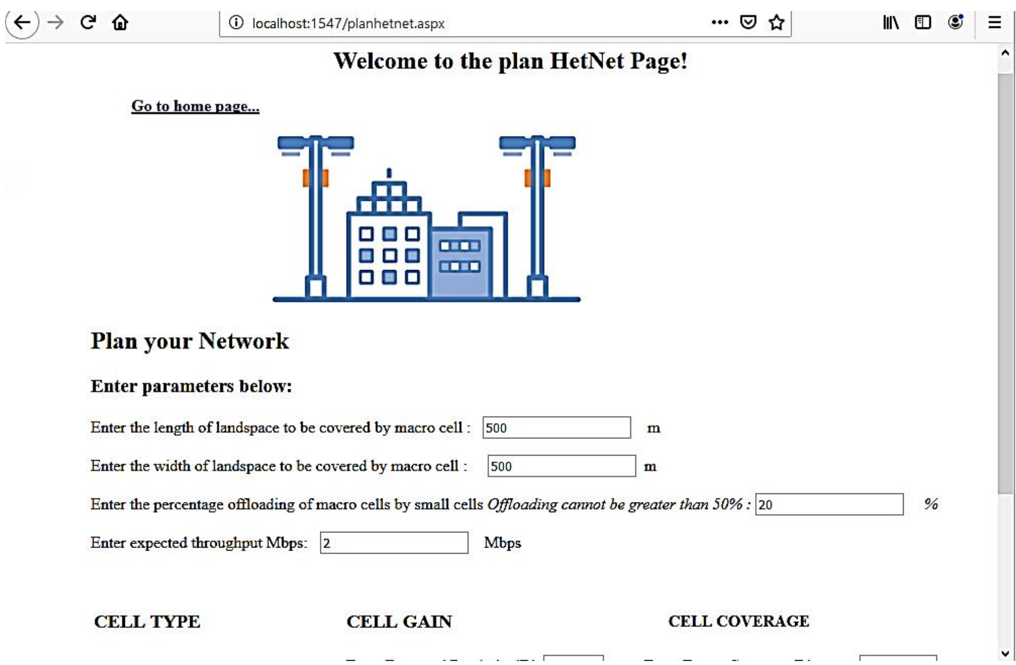

Figure 3 Screenshot of plan Het Net page

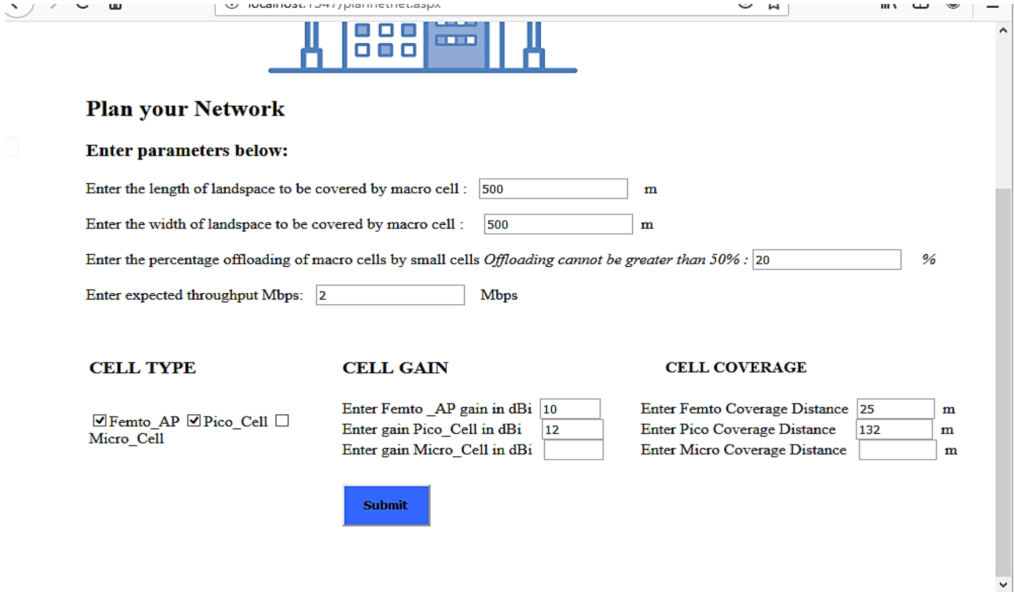

Figure 4 Screenshot of plan Het Net page (2)

Figure 5 Screenshot of plan Het Net Results page

Figure 5 shows the results of planning a heterogeneous network consisting specifically of Femto and Pico cells which is an improvement on the generic two-tier models put forward by [8].

4.Conclusion

In this paper some of the energy and network capacity problems in the mobile industry was solved by the developing equations that would aid in determining the network energy efficiency of heterogeneous networks, coverage and an interface that would enable ease of heterogeneous network planning/ deployment. These equations can be used to improve energy efficiency whilst improving spectral efficiency i.e., throughput. With signal processing power and spectral component of network elements remaining fixed (constant), it was discovered that increasing the number of cooperating BS can result in a reduction in Energy Efficiency i.e., more heterogeneity, more energy efficiency and overall better QoS. The equations/models were implemented using the developed software and would aid network operators and private individuals during network deployments ahead of the expected small cell introduction in future.

Nomenclature

A coverage area of the macro-based cell
af area of femto-cell
am area of micro-cell
ap area of pico-cell
B Breadth of area under consideration
G directive gain
L length of area under consideration
m number of small cell category involved in offloading, NOTE THAT m<=3
n number of cells required to cover area *A*
n number of small cells required to offload macro-BS
nEE Network energy efficiency
Nu mean number of UE's in cell coverage area
P_c Total Power consumption
P_f Static Power consumption
P_t Transmitting power of base station
r radius of coverage
R Radius of coverage area under interest
R radius of coverage
RB radius of macro-cell
Rf radius of Femto-cell
Rm radius of Micro-cell
Rp radius of Pico-cell,
Tr Traffic in Erlang
Y offload factor of macro cell (note that ϒ cannot be greater than 0.5)
λk mean number of UE's in coverage area of interest

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