

Optimized energy-aware cellular network planning with random waypoint user mobility

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ABSTRACT

In this work, we aim to plan an energy-efficient cellular network that can take into account minimizing the cost and energy of the whole network and minimizing the distance between user and base station. Also, it takes the mobility of users into account using the random waypoint method to represent the user mobility. The design strategy depends on turning off as many base stations as possible to reduce the consumed power while keeping full or partial coverage and quality of service over the serviced area. We have implemented all work by using Matlab software.

Keywords: Green Network Planning, Energy-aware cellular network, optimized cellular network planning.

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1. Introduction

A large part of the consumed energy in the cellular network is dissipated in Base Stations (BSs). If it is possible to switch off some BSs, we can reduce the energy consumed; such system design was proposed by [1], with fixed traffic of the users. In [2], the traffic is changed with time, so the authors turn off unnecessary BSs during the low traffic period. In [3], the authors assumed that there is existing macro BSs already deployed in The network surface area, and the micro BSs will deploy to satisfy the traffic capacity in the peak period. They proposed a greedy algorithm to deploy a set of micro BSs that can turn on in the peak time to satisfy the traffic capacity. Joint optimization was used in [4] to develop and operate cellular networks in order to reduce energy consumption while ensuring the quality of service and minimizing capital expenditures. The authors of [5] looked into the optimal control approach for 5G networks' Advanced Sleep Modes (ASM). A new feature called BS switching was introduced. ASM is a set of sleep modes that range from a few microseconds of deactivation to the complete shutdown of the base station for a few seconds or more. Based on the meta-heuristic algorithm discussed in [6] using Particle Swarm Optimization (PSO) and Gray Wolf Optimization (GWO), In order to choose the best sites for BSs, the Authors consider the coverage and capacity of the network. After that, remove the redundant BSs so that the network can function with a minimum number of BSs. From all mentioned above, we try to solve the problem from the beginning (planning stage); the big challenge is what type of BSs will be used and where to locate according to the users' positions and traffic in an efficient way that guarantees minimum cost for the network operator and minimum power consumed in the network with varying user demand and location in each period. We don't assume there are any BSs deployed previously, and the only thing to know is the daily traffic. There is a lot more to this paper than that. Section II focuses on system design. Section III describes the mobility of a random waypoint, while section IV presents the results. This is the fifth paragraph of Section V that presents the discussion. Finally, VI conclusion.

1.1. System modelling

To design a cellular network, we need to specify the BSs locations and the type of each one of them according to the two main constraints, first, the traffic constraint, which is essential to determine the BS capacity, second is the coverage constraint to ensure that all area is covered with the primary coverage signal. Planning 2G and 3G can be found in [7] and [8], respectively. Our system model contains two types of test points sets. The first set generates traffic demand that represents the users, and each point (user) has a traffic demand that must be met from the BS, which we will call (U_x). And the second set ensures that the point is covered by BS, which we call (C_x). We deploy it every 200 meters in each direction in the area. We assume that each U_x has random traffic demand from 20 to 40 Mb/s. For the BSs locations, we will use a set of candidate sites (CS), which represent where we can install the BS. Then we select the optimum locations among them to install our BSs to satisfy user traffic demand and coverage. Furthermore, we must select the type of BS to install in each selected location; assuming there are three types of BS to install; the system selects the optimum type for each location depending on the demand traffic and the basic coverage to meet the applicable requirements. The three types of BS to select are Macro, Micro, and Pico base stations. We will install one of these three types of BS in each selected location. The details of each type of BSs are illustrated in Table 1.

Table 1. BSs details

	Macro BS	Micro BS	Pico BS
CaPex	30 k€	10 k€	1 k€
On state Required Power	1350w	144.6w	14.7w
Capability	210Mb/s	70Mb/s	70Mb/s
Range of Coverage	1230m	850m	241m

Table 1 above gathers all values we need for base stations in the modelling to calculate the cost, consumed power, and coverage radius to examine if the user is covered by BS. Values in Table 1 are extracted from[9]. To build a real network, we assume that the demand traffic changes every period in the day hours, so we will consider that we have a residential area, so the demand profile in Table 2, extracted from [10], will be considered our daily traffic profile. We also generate a random number between 0 and 1 for each U_x . The random demand for each U_x previously generated will be regarded only if the random number is less than or equivalent to the demand traffic in Table 2 for each period.

Table 2. The modified daily traffic profile

period	from	To	Demand traffic
T1	0	2	0.8
T2	2	4	0.55
T3	4	8	0.25
T4	8	10	0.45
T5	10	13	0.65
T6	13	18	0.8
T7	18	20	0.9
T8	20	24	1

The general system variables are as follows

C_x : a set of nodes to test coverage.

U_x : a set of nodes to generate traffic in the area

C_s : a set of points in the area to locate BSs.

$B(C_s)$: types of BS can be located in one C_s

$T(t)$: time interval in the day

$D(U_x, t)$: data traffic demanded by U_x in interval T

$C(C_s, B)$: traffic capacity of BS with C_s location and type B

Cost (C_s, B): setting up price of BS installed in C_s of type B

$P(C_s, B)$: consumed power of BS installed in C_s of type B

Dist. (U_x, C_s): A measure of the distance from C_s to U_x

Pr (Ux, Cs, B): Three-dimensional array contains binary values to indicate that the Ux user is covered by BS installed in Cs of type B.

The following is a breakdown of the goals and restrictions.

$$\min. \sum_{Cs} \sum_B cost(Cs, B) X(Cs, B) + w_2 \sum_{Cs} \sum_B \sum_t P(Cs, B) T(t) Y(Cs, B, t) + w_3 \sum_{Ux} \sum_{Cs} \sum_t Dist(Ux, Cs) T(t) Z(Ux, Cs, t) \quad (1)$$

Subjected to:

$$\sum_{Cs} \sum_B Pr(Ux + Cx, Cs, B) Y(Cs, B, t) \geq 1 \quad (2)$$

$$Z(Ux, Cs, t) \leq \sum_B Pr(Ux, Cs, B) Y(Cs, B, t) \quad (3)$$

$$\sum_{Ux} Z(Ux, Cs, t) D(Ux, t) \leq \sum_B C(Cs, B) Y(Cs, B, t) \quad (4)$$

$$\sum_{Cs} Z(Ux, Cs, t) = 1 \quad (5)$$

$$Y(Cs, B, t) \leq X(Cs, B) \quad (6)$$

$$\sum_B X(Cs, B) \leq 1 \quad (7)$$

$$X(Cs, B), Y(Cs, B, t), Z(Ux, Cs, t) \in \{0,1\} \quad (8)$$

There are binary decision variables such as X (Cs, B) that is binary decision variables equal to 1 when the BS of type B is located in Cs and 0; otherwise, the binary decision variable Y (Cs, B, t) that is binary decision variable equal to 1 when the BS of type B is installed in Cs and is active in the int period T and the binary decision variable Z (Ux, Cs, t) equal to 1 when the user Ux is assigned to the BS in Cs during the int interval T, The first limitation (2) covers the entire region as a rule of thumb. As a result of constraint (3), every user Ux is assigned an active BS to which they can communicate, i.e., the mobile user is within the range of the BS. In order to accommodate the demands of users, a third constraint (4) is necessary, which is the capacity constraint. Each user must be assigned to just one base station if the user's position is covered via more than one base station under the fourth limitation (5). guaranteeing that only one type of BS can be picked for each of the three BSs in the fifth constraint (6). Finally, the three decision variables are made binary in the sixth constraint (7). According to a recently released study, existing topologies can benefit from power-saving approaches like cell sleeping based on energy-conscious principles. Even though new technologies could save money and the environment, mobile operators are reluctant to implement them due to the cost of the initial installation of these new technologies (CapEx). Premature replacement is less common with wireless base stations because of their extended lifespans. However, as mobile communications have extended across the globe, it has proven difficult to keep up with the ever-increasing traffic volume. An additional deposit of small cells over the existing infrastructure of bigger cells has been suggested to solve this problem. In legacy networks, massive, high-power BSs with restricted capacity per covered area is common, even when over-provisioned. In addition to their minimal installation and power consumption, Picocells' high data rate per unit of space makes them excellent applicants for network capacity enhancements without calling for significant investment from the mobile network operator. During times of lower traffic, such as at night, the picocells can be switched off because they only provide additional coverage during peak demand hours. Overall area coverage will not be affected by this. However, the crucial macro cells, which are the real culprits behind the high electricity costs, cannot be turned off due to their large radius and the resulting overlap with surrounding stations. As a result of this situation, a fundamental problem is brought to light. Topologies designed to save capital expenditures while keeping the most significant peak load capacity are not concerned with energy efficiency in cellular networks. The inflexible topological structure of a power control system, on the other hand, makes significant energy savings impossible.

2. Random waypoint mobility description

One of the earliest attempts to replicate intentional human movement is the RWP, which was first proposed by [11] to examine the performance of the routing protocol for Mobile ad-hoc networks MANETs. The RWP model might be a breakthrough in next-generation wireless network mobility modelling. The success of this mobility paradigm can be attributed to Dynamic Source Routing (DSR) protocol for MANETs. Wireless network models such as Ns2 (Ns2Team 2011), GloMoSim (Team 2011a), GTNetS (Team 2011b), etc., employ the RWP model as the default mobility model, making it the most extensively used model. The RWP proposed method would be the most extensively researched mobility method used in mobile cellular networks, and some of this method's key aspects are described in the literature. The static node spatial spreading and typical velocity of RWP mobile networks will be characterized in this study, following a standard formulation of the RWP mobility model. In addition to reporting the categorization of these qualities, we'll also provide a brief description of how they came to be. These examples from geometric probability and statistics should demonstrate to the reader how important they are in mobility modelling. The RWP model is part of synthetic, entity-based mobility models. Stochastic processes are used to represent the mobility of network nodes, in particular. Stochastic processes that govern the mobility of one individual node can be used to represent any number of mobile nodes in networks with the same number of nodes. Here, we describe a stochastic process in further detail. An informal definition of the RWP mobility model in a d -dimensional spatial domain R is to pick a random location for the node in R . Once the node has taken a predetermined pause time, the node selects a random destination in R , called the waypoint, and begins moving toward it with a constant speed V chosen randomly in an interval $[V_{min}, V_{max}]$. The node pauses at the waypoint for time t_p after reaching the waypoint. Next, the node goes in the same direction and pace as before, picking a new waypoint at random in R and following the same path to the new destination. These two additional parameters of the model control the node's trajectory.

Stochastic process: RWP mobile node is characterized by this stochastic process

Assuming that (I) is 1, 2, 3, 4, and so on, the random variables representing the coordinates of the i th waypoint are d -dimensional random variables referred to as ' D_i ,' ' T_i ,' and ' V_i ,' respectively. In the original RWP definition, D_i is distributed equally on R , T_i is a constant equal to t_p , and V_i is selected uniformly at random in $[V_{min}, V_{max}]$. D_0 is chosen at random in R and the rest of the nodes.

There are two things to note concerning the mobility of RWPs:

First, for a convex area R , an RWP mobile node's trajectory never exceeds the boundary of R . This indicates that RWP mobility does not necessitate a specific border regulation. Second, the RWP mobile nodes' trajectories are more likely to cross the centre of the RWP domain than to cross its borders. According to the RWP model, stationary node spatial distribution in a confined domain is not uniform: RWP mobile nodes are more likely to be located in the centre than on the borders of R . As a result of the fact that nodes move inside a finite spatial domain, the border effect causes a decrease in spatial node density on the border. This means that the RWP model would not suffer from the border effect, provided the spatial movement domain was unbounded or toroidal (think of nodes moving on Earth). Final observation: the border effect exists even when a mobile node never crosses the boundary of R with bound RWP mobility. This means that trajectories reaching the border and defining a border rule are unnecessary causes of the border effect. The primary aspect of the RWP method researched in the literature is the spatial spreading of stationary nodes. It was first seen and quantified in simulation-based research [12]. After that, the border effect was formally characterized by derivation of the stationary node spatial spreading. Readers who are unsure of the significance of defining the stationary node spatial spreading in a mobility model may wish to hold off on asking any further questions. Simulation accuracy can be seriously harmed because a stationary node spatial spreading differs from the nodes' initial distribution (usually random uniform). Figure 2 illustrates the RWP mobility pattern for one user movement.

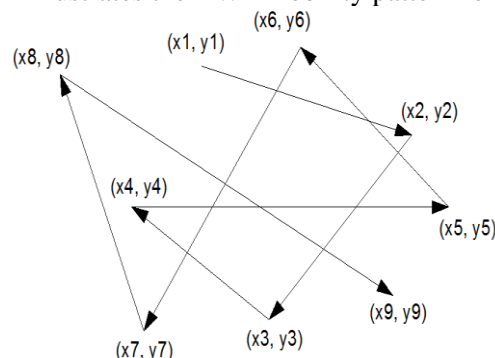


Figure 1. RWP mobility for one user

3. Practical solution and results

Matlab can solve this problem by representing the objective function and constraints and selecting an appropriate solver. Our binary-linear problem may be solved using "intlinprog," in which equality and inequality constraints are applied to minimize the objective function in order to solve linear integer optimization problems in Matlab.

W2 and W3 are two weighted factors in the objective function, which significantly impact the outcomes in the design and management stages. W2 denotes the influence for consumed electrical power in BSs, and W3 indicates distance (between user and base station). By experiment various variables to see how they affect the design. For network management, we rerun our system by using X (Cs, B) as input and deleting the cost section from our objective function after completing our design phase. At this point, we create a loop that includes all of the day's periods (network topologies) and analyzes each period's on/off state.

As a result, we can either run the network to provide full coverage to the serviced area, which is the regular management, or partially covered, which is done by removing the constraint (eq. 2) from the problem. The system switches on only the BSs with active users.

In the simulation, we assume that we have 30 Ux and 40 CSs with a squared area of 2km side length.

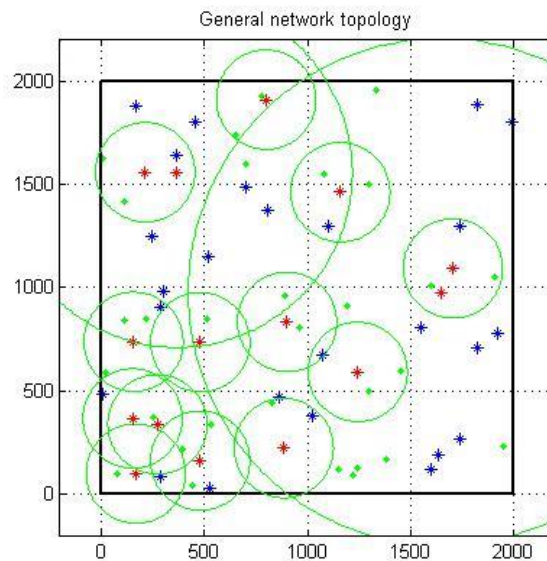


Figure 2. network planning with full coverage

In figure 2, the blue stars represent the unused CSs, the red stars represent used CSs, and the circles represent the covered area for the installed BSs, and the green dot is the Ux.

We have two options to manage the network, either full coverage or partial coverage, so we get different results if we apply these options.

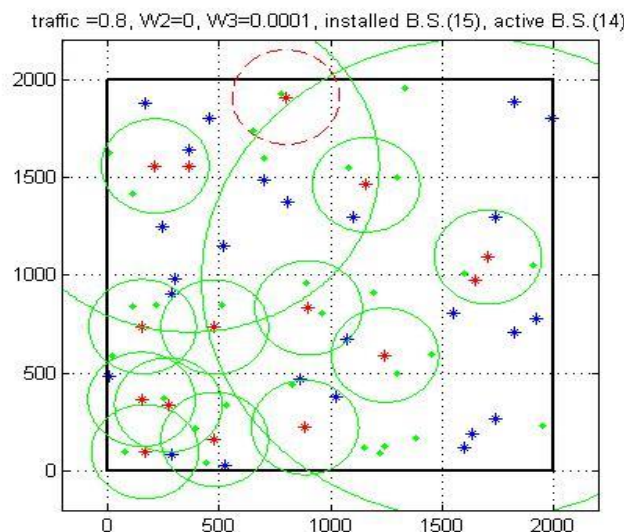


Figure 3. active BSs for periods T1 and T6 for traffic 0.8 with full coverage

In Figure 3, we have run the network with 0.8 traffic with full coverage and $W2=0$, $W3=0.0001$ to the serviced area, and we have 14 BSs in the on state and just one BS in the off state (dashed red circle).

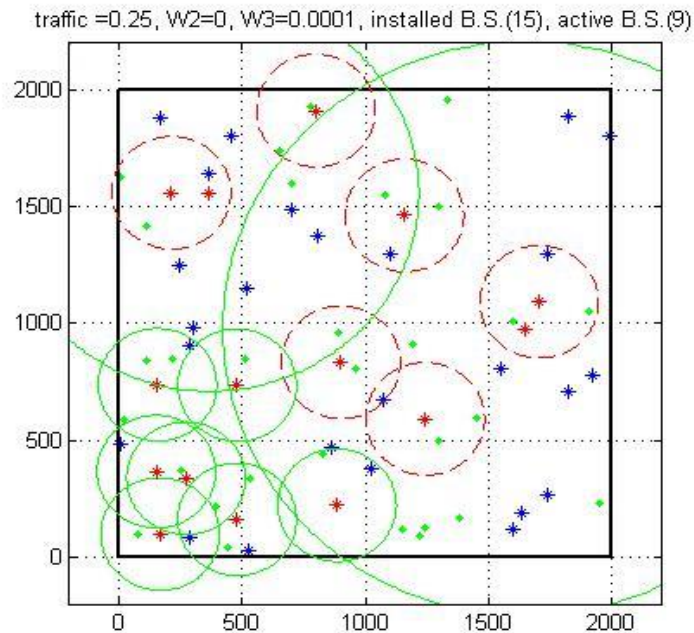


Figure 4. active BSs for period T3 for traffic 0.25 with full coverage

In Figure 4, we have run the network with 0.25 traffic with full coverage to the area and $W2=0$, $W3=0.0001$ we have 9 BSs in the on state and 6 BSs in the off state.

We apply the management system to the rest periods in the day to evaluate the on/off state of the BSs and calculate the consumed power in the day. Also, calculate the total cost for each case when the two factors are changed.

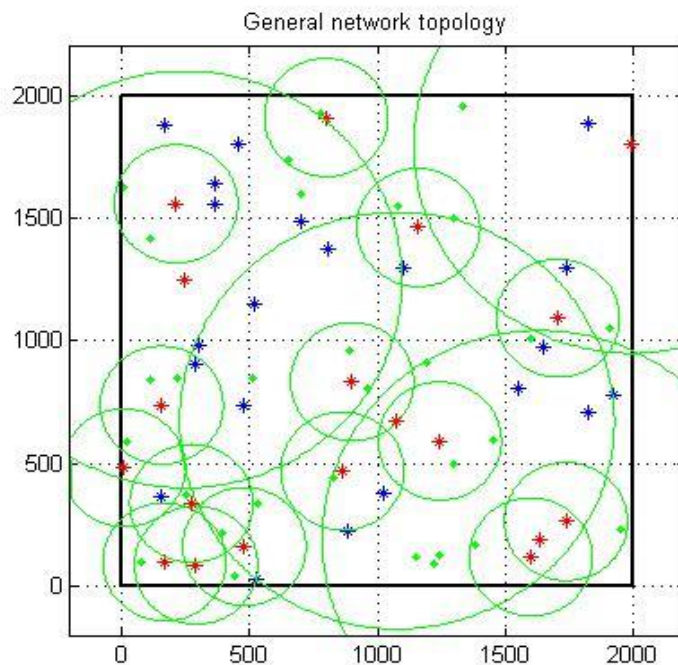


Figure 5. network planning with full coverage

In Figure 5, we change $W2$ and $W3$ to 1 and 0.001, respectively, then run the system with the identical CSs and U_x to examine the effect on the planning in the design stage and the consumed power in the management stage.

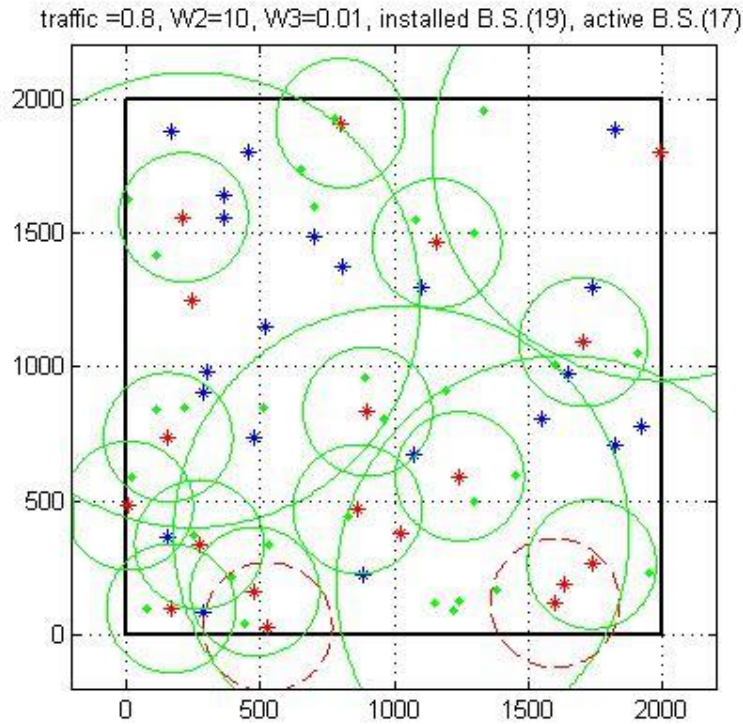


Figure 6. Active BSs for periods T1 and T6 with full coverage

In Figure 6, we have run the network with 0.8 traffic with full coverage to the serviced area and $W2=1$, $W3=0.001$, and we have 17 BSs in (on state) and 2 BSs in (off state).
 In figure 7, we have run the network with 0.25 traffic with full coverage to the area and $W2=1$, $W3=0.001$ we have 8 BSs in on state and 11 BSs in off state.

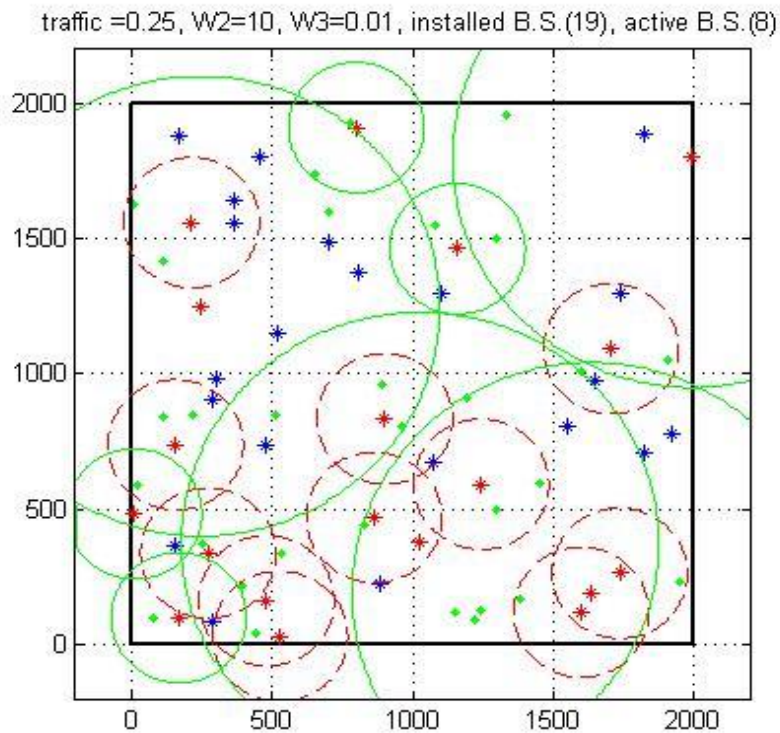


Figure 7. Active BSs for period T3 with full coverage

For partial coverage, we obtain the following results:

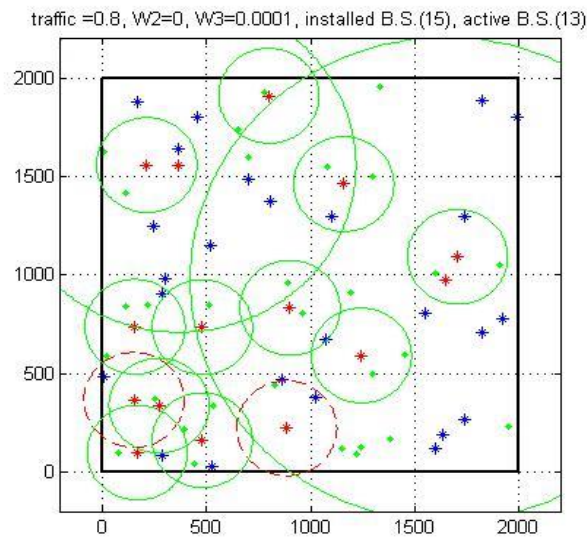


Figure 8. Active BSs for periods T1 and T6 with partial coverage

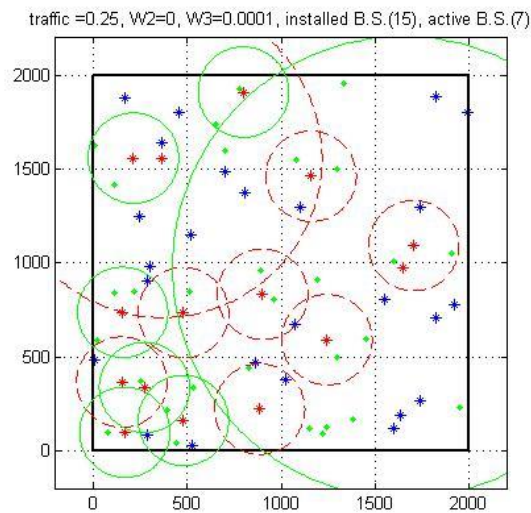


Figure 9. Active BSs for period T3 with partial coverage

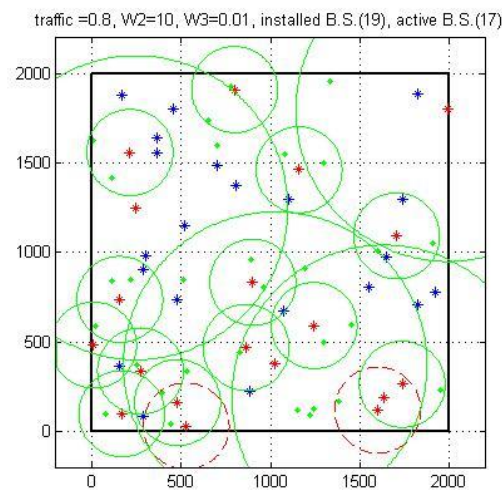


Figure 10. Active BSs for periods T1 and T6 with partial coverage

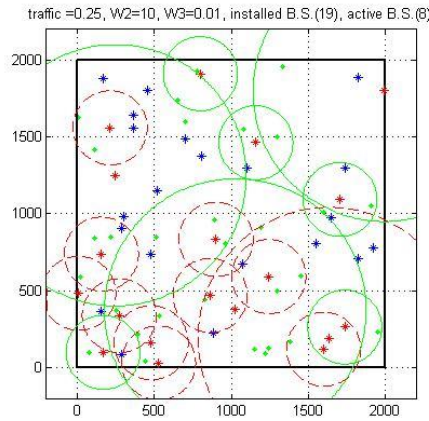


Figure 11. Active BSs for period T3 with partial coverage

In Figures 8, 9, 10, and 11, the management system provides coverage only for users, not the whole area, so we have minimum active BSs, which means we have minimum consumed power. It is noteworthy that the BSs need about 17ms to switch from active mode to sleep mode and vice versa [5]. Hence we can apply partial coverage management to mobile users, not only stationary users. Now we will use the more efficient way to manage the network in the case of mobile users. We assume that we have U_x every 400m in each direction in the design stage, so we have 36 U_x with random traffic from 20 to 40 Mb/s each to guaranty that we cover the whole area with relevant traffic. Furthermore, we choose the values $w_2=10$ and $w_3=0.01$. The results of our proposed management method as illustrated in the figures below.

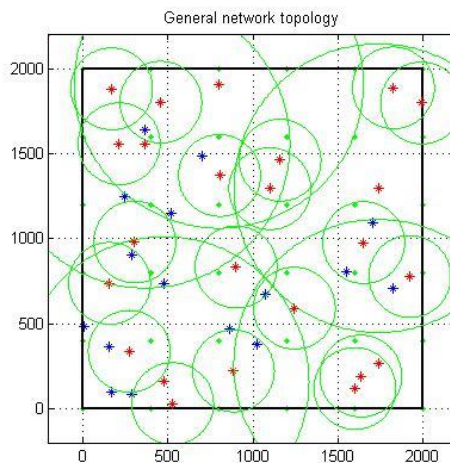


Figure 12. Network mobility planning with partial coverage

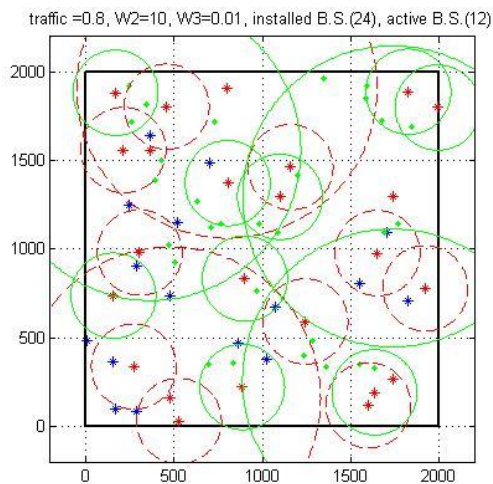


Figure 13. Active BSs for period T1 with mobility and partial coverage

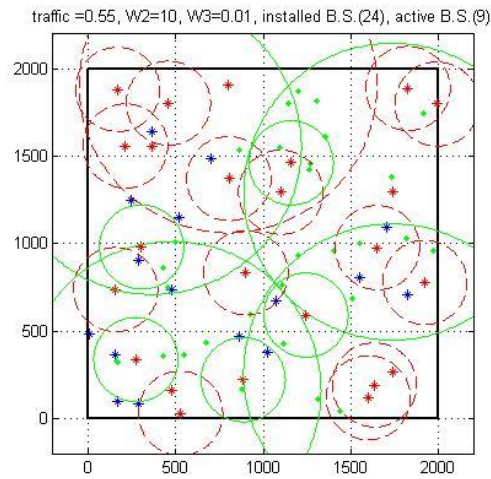


Figure 14. Active BSs for period T2 with mobility and partial coverage

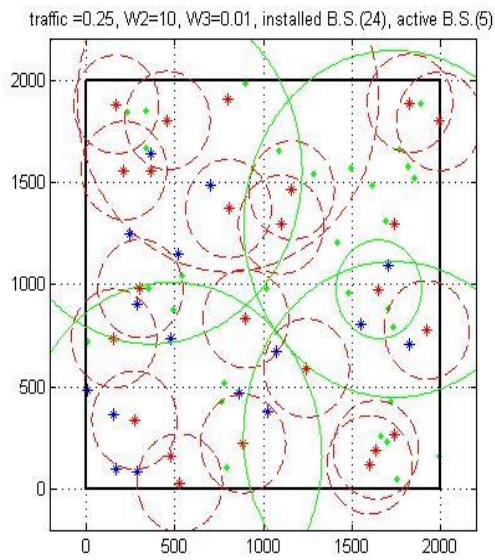


Figure 15. Active BSs for period T3 with mobility and partial coverage

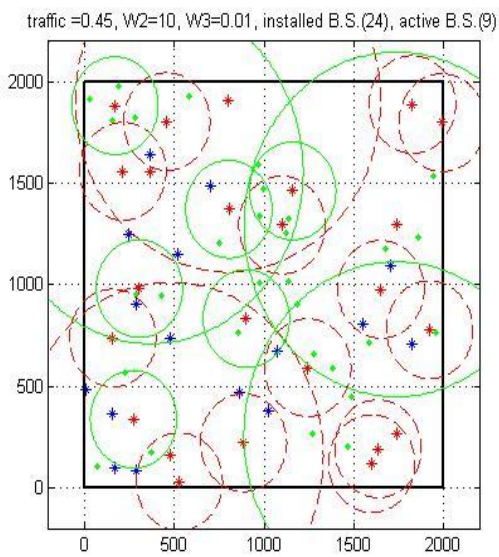


Figure 16. Active BSs for period T4 with mobility and partial coverage

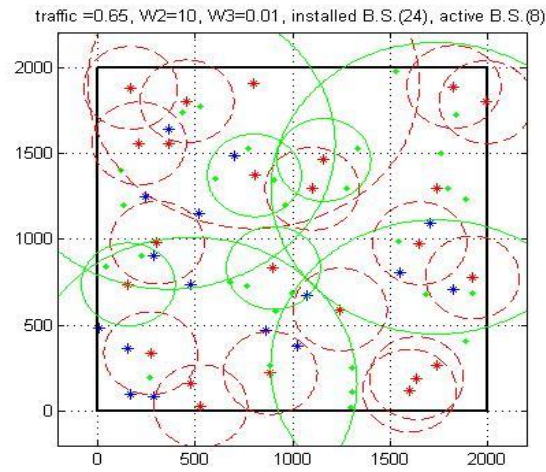


Figure 17. Active BSs for period T5 with mobility and partial coverage

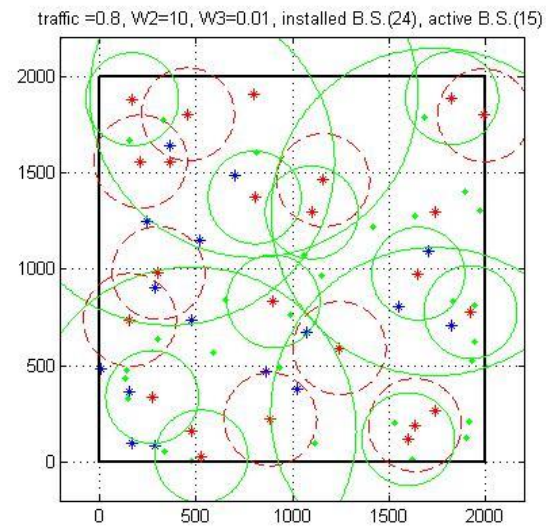


Figure 18. Active BSs for period T6 with mobility and partial coverage

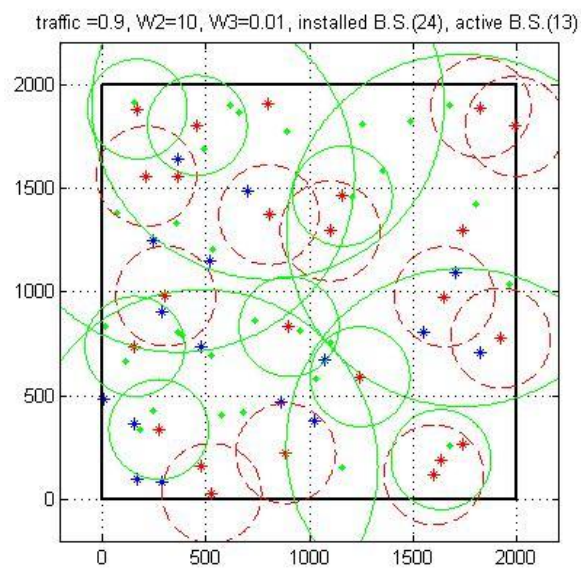


Figure 19. Active BSs for period T7 with mobility and partial coverage

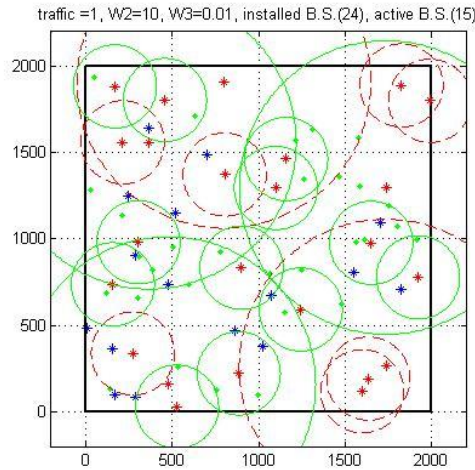


Figure 20. Active BSs for period T8 with mobility and partial coverage

Table 3. On/off state for BSs with daily consumed power for different cases of weighted factors

User type		Standing users		Standing users		mobile users
Weighted factors	W2	= 0		= 10		=10
	W3	= 0.0001		=0.01		=0.01
Type of coverage		Full	Partial	Full	Partial	Partial
Required Time (sec)		12.8	12.826	88.3	88.33	7204.8
price (k€)		53	53	55	55	69
Daily power (kw.h/d)		39.5895	38.1534	17.7183	16.3629	16.236
No. of BSs	Macro	=1	=1	=0	=0	=0
	Micro	=1	=1	=4	=4	=5
	Pico	=13	=13	=15	=15	=19
On BSs T1	Macro	=1	=1	=0	=0	=0
	Micro	=1	=1	=4	=4	=3
	Pico	=12	=11	=13	=13	=9
On BSs T2	Macro	=1	=1	=0	=0	=0
	Micro	=1	=0	=4	=3	=4
	Pico	=9	=9	=9	=10	=5
On BSs T3	Macro	=1	=1	=0	=0	=0
	Micro	=1	=0	=4	=3	=4
	Pico	=7	=6	=4	=5	=1
On BSs T4	Macro	=1	=1	=0	=0	=0
	Micro	=1	=0	=4	=3	=3
	Pico	=9	=8	=8	=10	=6
On BSs T5	Macro	=1	=1	=0	=0	=0
	Micro	=1	=1	=4	=3	=4
	Pico	=9	=7	=10	=12	=4
On BSs T6	Macro	=1	=1	=0	=0	=0
	Micro	=1	=1	=4	=4	=5
	Pico	=13	=13	=15	=15	=10
On BSs T7	Macro	=1	=1	=0	=0	=0
	Micro	=1	=1	=4	=4	=5
	Pico	=12	=11	=13	=13	=8
On BSs T8	Macro	=1	=1	=0	=0	=0
	Micro	=1	=1	=4	=4	=3
	Pico	=13	=13	=15	=15	=12

4. Discussion

It is clear from the data in Table 3 that if we run the system without power-awareness ($w_2=0$), we can expect a considerable amount of power consumption. However, when the power term is regarded in the design stage, the cost is lower than the other scenarios. As a result, the total cost (CapEx) and the network's power consumption must be balanced. Running the network management system in partial coverage also reduces power consumption because only BSs that have an active user are in the active mode at all times. The total cost of installation will rise to cover all locations with adequate capacity when user mobility is added to the system. When it comes to mobility, the on/off states are determined by the user's mobility and the demand traffic. We may have low traffic, but the distribution of users has spread over the area, resulting in a higher number of BSs being on at any given time. On the other hand, our area may have a high traffic demand but few on-state BSs, because of the limited space available to users.

5. Conclusion

Because of the increasing demand for telecommunications services, it is imperative to evaluate the ICT sector's energy effect and expand and modernize the supporting infrastructure. On the other hand, Mobile carriers suffer increasing costs due to the constant deployment and administration of new devices. Green networking is a major topic in the telecommunications industry right now. Researchers have looked into ways to lower the energy consumption of wireless networks by developing energy-efficient network designs and management. There is a connection between network design and proper energy efficiency that has been missed. A theoretical framework can attain installation and operational expenses. The CapEx and OpEx quantities can be traded off to generate multiple network topologies. An initial cost-effective network is installed if power costs are not considered; on the other hand, the optimization framework determines the best network topology based on its energy-saving operation if a little rise in initial cost is established. It is possible to identify a network topology that satisfies multiple constraints using the proposed optimization tool applied to any network topology. Particularly in the partial coverage situation, when active BSs only cover areas where active users are present, the network architecture can be affected by user mobility.

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