applied sciences

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On the Optimisation of Practical Wireless Indoor and Outdoor Microcells Subject to QoS Constraints

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Received: 24 July 2017 ; Accepted: 13 September 2017; Published: 15 September 2017

Abstract: Wireless indoor and outdoor microcells (WIOMs) have emerged as a promising means to deal with a high demand of mobile users for a variety of services. Over such heterogeneous networks, the deployment of WIOMs costs mobile/telecommunications company high capital expenditures and operating expenses. This paper aims at optimising the WIOMs taking into account various network communication environments. We first develop an optimisation problem to minimise the number of cells as well as determining their optimal locations subject to the constraints of the coverage and quality-of-service (QoS) requirements. In particular, we propose a binary-search based cell positioning (BSCP) algorithm to find the optimal number of cells given a preset candidate antenna positions. The proposed BSCP algorithm is shown to not only reduce the number of cells for saving resources but also requires a low computational complexity compared to the conventional approaches with exhaustive search over all available sites. Moreover, EDX SignalPro is exploited as a simulation platform to verify the effectiveness of the proposed BSCP for the WIOMs with respect to various propagation modes and antenna parameters of different types, including isotropic, multiple-input single-output and multiple-input multiple-output.

Keywords: wireless indoor microcells; outdoor microcells; MIMO; network planning; EDX SignalPro

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1. Introduction

Microcells along with macrocells have come a long way in mobile telecommunication industry to not only increase the capacity of the traditional cellular networks but also enlarge the coverage area of ultra-densed networks to support the distant area with low signal strength and high-mobility users [1–4]. The mixture of cells of different sizes forms a generalised network model of multiple overlaying layers or tiers, namely heterogeneous wireless cellular networks [2,5–12], which have been shown to provide higher data rate and enhanced coverage for indoor and outdoor mobile users.

Along with a number of advantages achieved with cell division approaches, the deployment of microcells raises a critical issue in cellular networks when the overlapping frequencies of different cells in the same area cause considerable interferences [13,14]. The overlapping coverage also implies the wastage of resources, whereas a smaller number of cells could be used to maintain the same coverage area. Network planning and optimisation therefore need to be considered in the implementation of microcells in practical cellular networks.

Recently, power control mechanism has been investigated with various power allocation and scheduling approaches to minimise the transmitted power at cells for mitigating interferences in cellular networks while still guaranteeing sufficiently received signal power at the mobile users [15–19]. However, considering the practical cellular networks, a number of buildings and mobile devices cause considerable fading, shadowing, noises and interferences. The signal-to-interference-plus-noise ratio is shown to be intractable for a heterogeneous network model and the conventional wireless cellular networks represented by hexagonal grids are too idealised to model the real networks [20,21].

Appl. Sci. **2017**, *7*, 948; doi:10.3390/app7090948

In order to model large-scale wireless networks, stochastic geometry has been exploited to develope tractable models that can not only realise the characteristics of the random network topology but also allow us to evaluate the performance of variant network models with tractable analytical results [20,22–27]. Although network planning and modelling have been studied in the literature with various approaches (e.g., [28–39]), their deployment in the practical heterogeneous networks has still raised a number of concerns to cope with various building structures, antenna specifications, location, etc., which to the best of the authors' knowledge has not been well investigated and optimised, and thus costs mobile/telecommunications company high capital expenditures and operating expenses.

In this paper, we investigate the optimisation of wireless indoor and outdoor microcells (WIOMs) in the practical networks subject to constraints of the coverage and quality-of-service (QoS) requirements. The main contributions of this paper can be summarised as follows:

- An optimisation problem is firstly developed to minimise the number of cells subject to the constraints of the required coverage and QoS at a specific area within a WIOM network. Given the fact that the locations for deploying the cell sites are restricted, the locations of these optimal cells are also required to be determined.
- A binary-search based cell positioning (BSCP) algorithm is proposed to not only find the optimal number of cells but also their optimal location given a preset candidate antenna positions. It is shown that the proposed BSCP allows us to determine the minimal number of cells with a low computational complexity compared to the conventional approach where exhaustive searches are utilised to iteratively validate all available locations for cell sites.
- EDX SignalPro [40] is exploited as a simulation platform to verify the effectiveness of the proposed BSCP for the WIOMs. Specifically, we consider various propagation modes of both indoor and outdoor environments with different antenna types, including single-input single-output (SISO), multiple-input single-output (MISO) and multiple-input multiple-output (MIMO). The proposed method can therefore be used for planning and optimisation of the WIOMs to reduce the waste of resources in terms of cost and power consumption.

The rest of this paper is organised as follows: Section 2 summarises related works on network planning and optimisation with various radio frequency (RF) simulation tools as a motivation for our work. Section 3 introduces the system model of WIOMs along with the optimisation problem of cell planning. Section 4 presents the proposed BSCP algorithm. Simulation results are illustrated in Section 5 to validate the effectiveness of the proposed algorithm. Finally, Section 6 concludes this paper with suggestion for future works.

2. Related Works

Network planning and optimisation are vital design requirements in practical cellular networks, especially when the number of mobile devices is dramatically increasing along with cell sites of different sizes and capacity. It is particularly crucial to consider various factors of communication environment in the network planning [35–39]. Specifically, in [35], an optimisation framework for selection and configuration of base stations were proposed based on simulated annealing algorithm. The finding of optimal position for base stations was also investigated in [36] where different optimisation problems were formulated as integer linear programs with respect to different objectives and constraints. Similarly, the simulated annealing was exploited in [36] as an approximate technique for solving the large-scale combinatorial optimisation problems. In [37], a greedy algorithm was proposed to select and configure base station locations given the candidate sites and multiple-objective genetic algorithms were exploited to find an optimal ordering of the potential base stations. Considering 3G cellular networks, the network planning was investigated in [38] where mixed-integer programming models were developed to determine where to install new base stations and how to select their configuration such as antenna height and tilt, pilot signal, maximum emission power, sector orientation, etc. Since the integer programming is non-deterministic polynomial-time (NP)-hard, a Tabu Search algorithm was adapted to provide approximate solutions with a lower computation complexity [38]. In [39], a combinatorial approach for optimising the location of the base stations was developed for the 4G systems with mixed cells and MIMO techniques.

There exist a number of approaches for radio planning using various simulation software programs, such as Actix Analyzer [41], Wireless InSite [42], WinProp [43], ComStudy [44], Broadband-eQ [45], Planet [46], deciBel Planner [47], WaveSight [48], EDX SignalPro [40], etc.

Specifically, Actix Analyzer [41] is one of the leading industry desktop solutions for radio frequency planning and optimisation, providing great visualization capabilities that enable engineers to analyze complex data in an effective and intuitive way for indoor and cellular networks. Exploiting ray-tracing models and high-fidelity solvers, Wireless InSite was developed in [42] for planning and optimisation of radio frequency. The Wireless InSite was shown to obtain accurate and efficient predictions of electromagnetic propagation and communication channel characteristics in complex urban, indoor, rural and mixed path environments. Some of its applications include predicting coverage, determining shadowing and multipath effect, assessing wireless backhaul solution and evaluating channel characteristic of various network models, e.g., 4G Long Term Evolution (LTE), LTE-Advanced, 5G [49] and indoor WiFi, with evolved techniques, e.g., MIMO and masive MIMO. Another software program, namely WinProp [43], was created to provide high accurate and fast analysis of the wireless propagation with applications ranged from rural to urban, from indoor to outdoor, from satellite to terrestrial, etc. Along with the above professional software, a simple software named ComStudy [44] was designed by Radio soft company as a complete and easy-to-use solution for all radio engineering and spectrum needs; however, it is not powerful for design engineers to cope with practical network design issues.

Dealing with sophisticated radio propagation modeling for voice and data, Broadband-eQ was developed in [45] for network optimisation and management. The Broadband-eQ also allows us to evaluate the coverage and capacity, mitigate interference, analyse grade of service and throughput, with automated frequency allocation towards next generation technologies. With the requirement of live mobile network planning, Planet was built in [46] and has been used by many mobile network operators. Planet can support most wireless access standards in small cells and heterogeneous networks with different advanced technologies and antenna modelling using antenna library provided by the vendor. Considering the practical geographic information system (GIS) in the radio propagation and modelling, deciBel Planer [47] is the first software program that can be fully integrated with Mapinfo providing flexible network planning taking into account GIS data. While most software programs are based on 2D modelling, WaveSight [48] was developed as a complementary module with ray-tracing 3D building databases that can be used to provide the most accurate network coverage analyses in different infrastructures and network layers, e.g., microcells and macrocells.

A number of research works have been dedicated to the network planning with various tools and approaches. As a supplement to the state-of-the-art works, this paper investigates the network optimisation subject to both network coverage and QoS requirements with restricted cell site location. Specifically, a new BSCP algorithm is proposed to find the optimal number of cell sites along with their corresponding location among the preset candidate cell positions. In the scope of this work, EDX SignalPro (version 7.4.0 B, EDX Wireless, Eugene, OR, USA) is selected to validate the effectiveness of the proposed algorithm due to its efficiency in providing free-trial planning tools for wide area service prediction, link analysis, point-to point and point-to-multipoint studies [40].

3. System Model of WIOMs and Network Optimisation Problem

Figure 1 illustrates a typical WIOM network where the microcells are deployed either within a house/building or in large exterior area of many buildings in a 2D grid. (In this work, only a simplistic network model is considered; however, it can be extended to a more general network with geographical database (or geodatabase) following the same approach with the proposed cell planning algorithm which will be shown in the following section.) From a practical point of view, it is assumed there are a total of N candidate locations that are restricted for placing cell sites in an area under investigation and the maximum number of cell sites that can be employed is $K_{\max}$ ($K_{max} \leq N$). Let $\mathfrak{S}$ denote the set of coordinates of these candidate cell sites, i.e., $\mathfrak{S} = \{(x_1, y_1), (x_2, y_2), \ldots, (x_N, y_N)\}$.

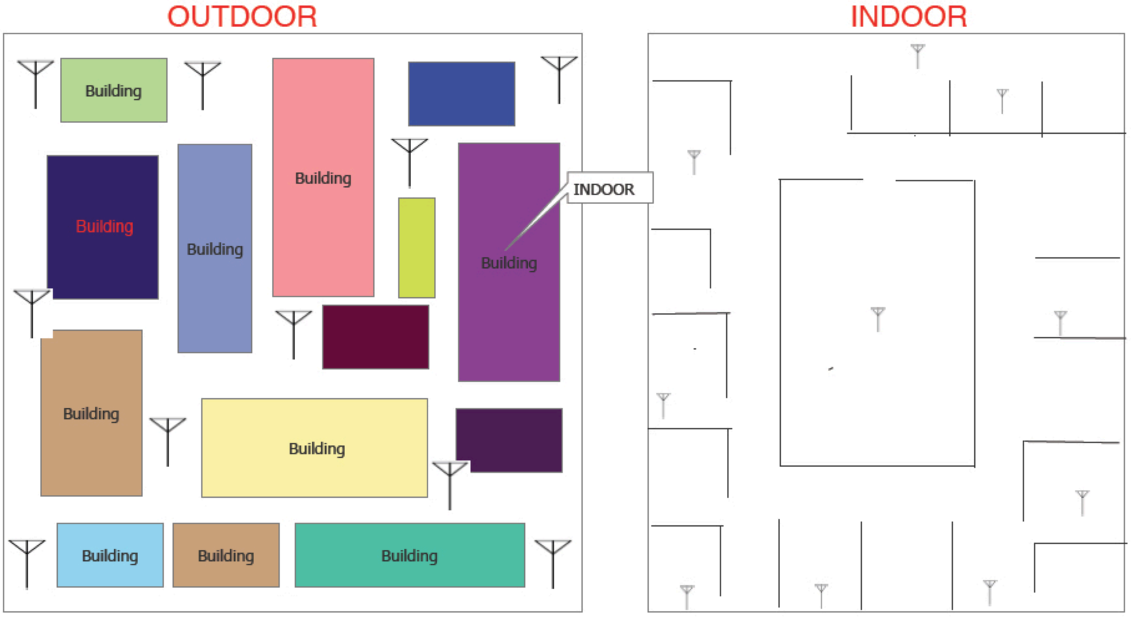

Figure 1. System model of Wireless indoor and outdoor microcells (WIOMs).

To meet the QoS requirements, it is required that M areas in the WIOM network are all covered. For simplicity, the m-th area, $m = 1, 2, \ldots, M$, is represented by a point (x_{e_m}, y_{e_m}) in a set $\mathfrak{S}_E = \{(x_{e_1}, y_{e_1}), (x_{e_2}, y_{e_2}), \ldots, (x_{e_M}, y_{e_M})\}$. The network optimisation problem (NOP) can be formulated as

$$\min_{\substack{k \in [1, K_{\max}] \\ \mathfrak{S}_{i_k} \subset \mathfrak{S}}} k, \tag{1}$$

$$\text{s. t. } P(x_{e_m}, y_{e_m}) \geq P_{\min}, \forall m = 1, 2 \ldots, M, \tag{2}$$

where $\mathfrak{S}_{i_k}$ is a subset of $\mathfrak{S}$ consisting of k elements, $P(x_{e_m}, y_{e_m})$ is the received power at (x_{e_m}, y_{e_m}) and $P_{\min}$ is the minimum received power requirement in the considered area. Here, the received signal strength indicator is based on the QoS requirements [50]. Note that $\mathfrak{S}$ has a total of 2^N subsets and there are $\binom{N}{k}$ ways to choose a subset of k elements.

The NOP in Equation (1) is to find the minimum number of cell sites, i.e., $k_{\min}$, in the range $[1, K_{\max}]$ as well as their optimal position, i.e., $\mathfrak{S}_{i_{k_{\min}}}$ among the available positions in the set $\mathfrak{S}$. The received power at each point (x_{e_m}, y_{e_m}) in the set $\mathfrak{S}_{\mathfrak{E}}$ needs to meet the QoS requirement in Equation (2), which also reflects the required coverage area.

In order to solve the above NOP, it is worth mentioning that an exhaustive search can be employed, namely exhaustive-search based cell positioning (ESCP). However, such an ESCP algorithm requires a high computational complexity to perform a number of iterations and simulation runs over all possible candidate locations with different numbers of cell sites, especially when considering a large number of candidate cell positions. Therefore, in the following section, we aim at proposing a novel algorithm for cell site searching, which will be shown in Remark 1 that a lower complexity can be achieved with the proposed algorithm when compared to the ESCP algorithm.

4. The Proposed Binary-Search Based Cell Positioning Algorithm

It can be noticed that different cell sites may have different coverage areas depending on their antenna characteristics, power allocation as well as practical locations. The cell sites can be therefore sorted in order of the coverage area. In this case, the binary search approach has been shown to provide a faster searching compared to the conventional iterative search without sorting [51]. This accordingly motivates us to propose a BSCP algorithm in this section to solve the NOP in Equation (1) subject to the constraint in Equation (2) following the binary search approach.

We first order the cell sites according to their coverage area. Let A_{c_k}, $k = 1, 2, \ldots, K_{\max}$, denote the measured coverage area of the k-th cell site. Without loss of generality, let us assume that $A_{c_1} \leq A_{c_2} \leq \cdots \leq A_{c_{K_{\max}}}$.

Notice that there are a total of $T = \sum_{k=1}^{K_{\max}} \binom{N}{k}$ possibilities of placing cell sites on N candidate locations. A special case is if $K_{\max} = N$, then $T = 2^N - 1$. Let $\mathfrak{S}_T$ denote the set of these combinations with the corresponding set of the ordered coverage area $\mathfrak{B}_T = \{B_{c_1}, B_{c_2}, \ldots, B_{c_T}\}$.

In the proposed BSCP algorithm, the key idea is that we start searching from the middle element of the data set $\mathfrak{S}_T$ and validate the constraint in Equation (2). If the constraint is not satisfied, then we eliminate the lower half of $\mathfrak{S}_T$ and continue with the search of the remaining upper half of $\mathfrak{S}_T$; and vice versa. The search will stop when the remaining set is null. The optimal coverage area, i.e., B_{opt} in $\mathfrak{B}$, the optimal locations for cell sites, i.e., $\mathfrak{S}_{i_{k_{\min}}}$ in $\mathfrak{S}_T$, and the minimum number of cell sites, i.e., $k_{\min} = |\mathfrak{S}_{i_{k_{\min}}}|$, can be accordingly determined. Here, $|\cdot|$ denotes the cardinality of a finite set. The proposed BSCP algorithm is summarised in Algorithm 1 and, for clarity, the flow chart for this algorithm is illustrated in Figure 2.

Algorithm 1 BSCP Algorithm for WIOM Planning.

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Require: $N$, $K_{\max}$, $P_{\min}$, $\{A_{c_k}\}$, $k = 1, 2, \ldots, K_{\max}$: $A_{c_1} \leq A_{c_2} \leq \cdots \leq A_{c_{K_{\max}}}$
Sort the coverage area of the $T = \sum_{k=1}^{K_{\max}} \binom{N}{k}$ possibly combined cell sites: $\mathfrak{B} = \{B_{c_1}, B_{c_2}, \ldots, B_{c_T}\}$
Set $i_L \leftarrow 1$, $i_U \leftarrow T$ {smallest and biggest indexes of $\mathfrak{B}$}
repeat
    Set $i_C \leftarrow \lceil (i_L + i_U)/2 \rceil$ {index of midpoint of $\mathfrak{B}$}
    if $P(x_{e_m}, y_{e_m}) \geq P_{\min}, \forall m = 1, 2, \ldots, M$ then
        $i_U \leftarrow i_C - 1$
    else
        $i_L \leftarrow i_C + 1$
    end if
until $i_L > i_U$
return $B_{opt} = B_{c_{i_C}}$, $\mathfrak{S}_{i_{k_{min}}} = \mathfrak{S}_{i_C}$, $k_{\min} = |\mathfrak{S}_{i_{k_{\min}}}|$
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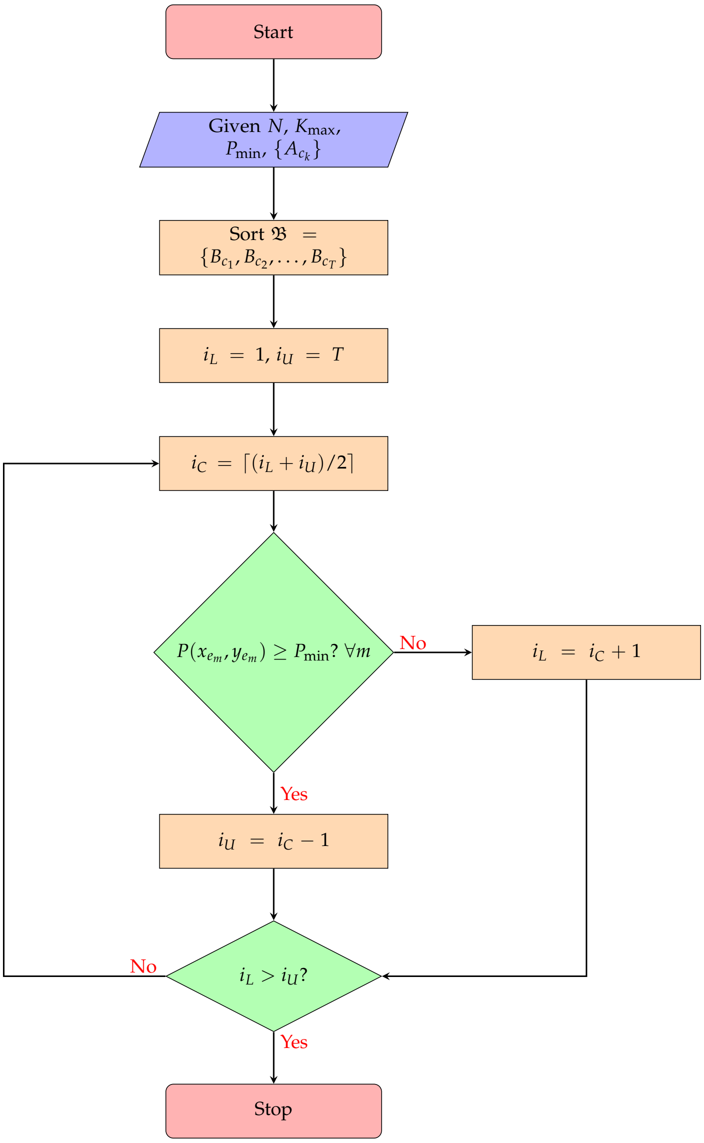


Figure 2. Flowchart of the binary-search based cell positioning (BSCP) Algorithm.

Remark 1 (Complexity Analysis)**.** *Generally, with binary search, finding an item in a sorted array of n elements requires $\mathcal{O}(\log n)$ comparisons in the worst case scenario, while a linear or exhaustive search over all elements takes $\mathcal{O}(n)$ time [51]. As shown in Algorithm 1 for WIOM planning, the proposed BSCP performs the binary search over a set consisting of $T = \sum_{k=1}^{K_{\max}} \binom{N}{k}$ elements which correspond to the possibilities of placing cell sites on N candidate locations. Therefore, the BSCP algorithm requires a total of $\mathcal{O}(\log T)$ comparisons, which is of lower complexity than the conventional ESCP algorithm with $\mathcal{O}(T)$ time for linear search. For example, let us consider a special scenario when $K_{\max} = N$, then $T = 2^N - 1$. In this case, the BSCP and ESCP algorithms require $\mathcal{O}(N)$ and $\mathcal{O}(2^N)$ operations, respectively, which accordingly means that a much lower complexity can be achieved with the proposed BSCP over the ESCP algorithm, especially when the number of candidate locations is large.*

5. Simulation Results and Evaluation

In this section, simulation results of network planning for wireless indoor and outdoor microcells are provided. EDX SignalPro is exploited to evaluate the coverage area using the proposed ESCP algorithm (Note that, apart from EDX SignalPro, the proposed algorithm can be validated using other simulation software or tools. The free-trial version of the EDX SignalPro is used in this paper for cost effectiveness, although this version has some restrictions that limit its applicability for different network models.). For comparison, we consider both the scenarios when all available microcells are deployed and when the optimal number of microcells are located using our proposed BSCP algorithms (The ESCP algorithm would result in the same performance and is thus omitted for brevity. It should be reiterated that the ESCP requires a higher complexity compared to the proposed BSCP algorithm) with different antenna types, including SISO, 2 × 1 MISO and 2 × 2 MIMO employing space-time coding. A small network is considered where it is assumed that there are six candidate locations for placing the antennas in both the wireless indoor and outdoor microcells. The BSCP algorithm is employed to find the optimal number of antennas and their optimal locations (see Equation (1)) to cover the required area subject to the constraint in Equation (2).

5.1. Wireless Indoor Microcells

Let us first consider cell planning for wireless indoor microcells. Table 1 shows the simulation parameters for wireless indoor environment using EDX SignalPro software. Specifically, the type of antenna used at both cell site and receiver unit is omnidirectional isotropic. Antenna height is 3 m for cell site and 2 m for receiver unit. The antenna polarization is set to horizontal for transmitter and vertical for receivers having cross polarization attenuation of 0 dB and 15 dB, respectively. The equivalent isotropically radiated power (EIRP) at the transmitter of the cell site is set as −12 dBm. Both the transmitter and receiver operate at Wi-Fi 802.11a/g.

Table 1. Simulation parameters for wireless indoor microcells.

RF Parameters at Transmitter of a Cell Site	**Values/Description**
Antenna pattern	omnidirectional isotropic
Antenna height	3 m
Antenna polarization	horizontal
Cross polarization attenuation	0 dB
Transmitter type	Wi-Fi 802-11a/g
Effective isotropic radiated power (EIRP)	−12 dBm
RF Parameters at a Typical Receiver	**Values/Description**
Antenna pattern	omnidirectional isotropic
Antenna height	2 m
Antenna polarization	vertical
Cross polarization attenuation	15 dB
Receiver type	WiFi 802-11a/g
Receiver noise system noise figure	4.0 dB
Receiver noise level	−97 dBm
Equivalent receiver noise bandwidth	20 MHz
Adjacent channel rejection	40 dB

Figure 3 illustrates an indoor area that needs to be covered by wireless indoor microcells. It is assumed that there are six candidate antenna positions, i.e., $N = 6$, and 23 required coverage areas, i.e., $M = 23$, which are marked by blue circles and yellow stars, respectively. The maximum number of cell sites that can be deployed is set as $K_{\max} = 6$. Here, the colour range of received power at remote indoor units is defined in Figure 4 and the power received at the remote unit in the marked coverage areas is required to be at least −65 dBm, i.e., $P(x_{e_m}, y_{e_m}) \geq -65$ dBm, $\forall m = 1, 2, \ldots, 23$ (see Equation (2)). It can be observed in Figure 3 that if all six available antennas are used at all candidate positions, then all the required coverage areas are shown to ascertain the QoS requirement. However, a considerable overlapping area can be noticed with the usage of all the available resources. In this work, we therefore aim at saving the resources by finding the minimum number of microcells that can still cover the same area.

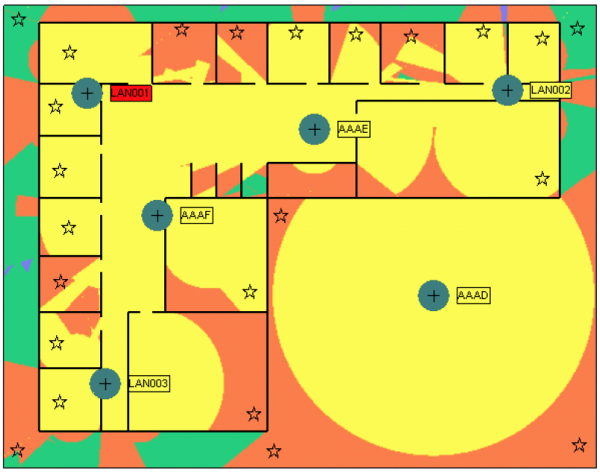


Figure 3. Wireless indoor microcells with six candidate antenna positions and required coverage areas.

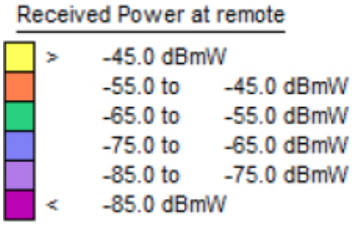


Figure 4. Colour range of received power at remote indoor.

Considering SISO antennas, Figure 5 illustrates the optimal site locations for indoor using the BSCP algorithm. It can be observed that, with four SISO sites, all the marked areas in Figure 3 are covered satisfying $P(x_{e_m}, y_{e_m}) \geq -65$ dBm, $\forall m = 1, 2, \ldots, 23$. This accordingly reflects the effectiveness of the cell planning with the BSCP algorithm in saving two cell sites for both cost and energy consumption reduction when compared to the case when all six antennas are deployed.

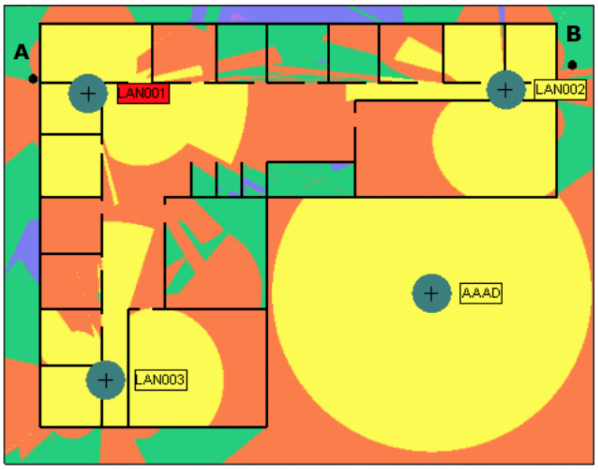


Figure 5. Heuristic site locations for indoor with single-input single-output (SISO) antennas.

Employing multiple antennas at the sites and/or remote units, Figures 6 and 7 sequentially elucidate the optimal site locations with MISO and MIMO antennas to cover the same area as in Figure 3. It can be seen in both Figures 6 and 7 that the BSCP algorithm results in the same number of sites, i.e., four MISO sites or four MIMO sites, to cover all the marked areas due to their strict

QoS requirements, although a higher coverage area is literally achieved with the multiple antenna deployment. Specifically, taking into account two specific areas marked as **A** and **B** in Figures 5–7, it can be observed that the received power at these areas is in the range of $[-65, -55]$ dBm when employing the SISO antennas, while the MISO can provide a higher signal strength of $[-55, -45]$ dBm and the MIMO with higher than -45 dBm.

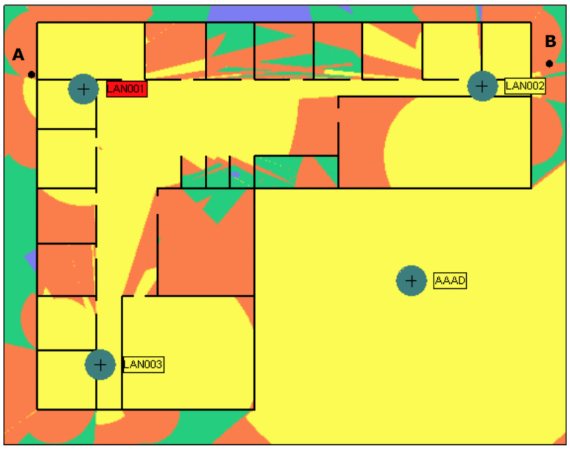


Figure 6. Heuristic site locations for indoor with multiple-input single-output (MISO) antennas.

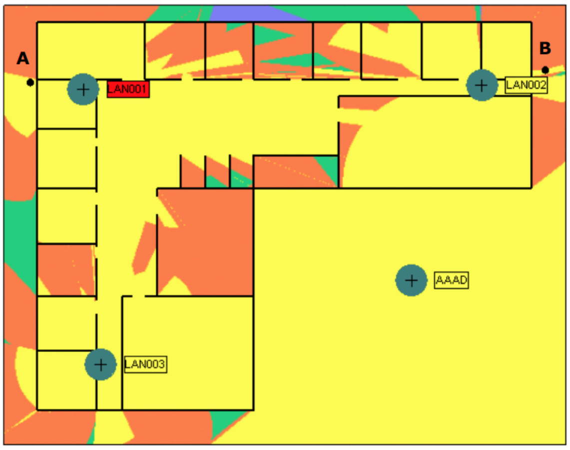


Figure 7. Heuristic site locations for indoor with multiple-input multiple-output (MIMO) antennas.

5.2. Wireless Outdoor Microcells

Taking into account the outdoor environment, Table 2 provides a list of key simulation parameters for wireless outdoor microcells. Specifically, the RF at transmitter of a cell site consists of the following major components: antenna pattern is omnidirectional isotropic, transmitter frequency is 850 MHz, transmitter antenna height is 30 m, the antenna polarization is horizontal with cross polarization attenuation of 0 dB and the EIRP is set as -14 dBW. The parameters at receiver units are similarly set as in Table 1 for the indoor scenario.

Figure 8 illustrates the area that is required to be covered by wireless microcells. For the outdoors, buildings may have different heights that are represented through a colour range defined in Figure 9a, while the range of the received power at remote units are defined in Figure 9b. It is assumed that there are six positions available in the area for site installation, i.e., $N = 6$, which are marked by yellow circles. It is further presumed that 16 required coverage areas, i.e., $M = 16$, marked by red stars should be covered to guarantee that most of the areas are bounded. The maximum number of cell sites available is also set as $K_{\max} = 6$ and the received power at the remote unit is required to be at least -95 dBm, i.e., $P(x_{e_m}, y_{e_m}) \geq -95$ dBm, $\forall m = 1, 2, \ldots, 16$. In the scenario that all the available resources are used, all the required coverage areas are shown to meet the QoS requirements, but it can also be seen in Figure 8 that there exists areas having higher received power as required. In order to save network resources, it is vital to find an optimal solution to cover the area meeting the QoS requirements with a minimum number of cell sites.

Table 2. Simulation parameters for wireless outdoor microcells.

RF Parameters at Transmitter of Cell Sites	**Values/Description**
Antenna pattern	omnidirectional isotropic
Antenna height	30 m
Antenna polarization	horizontal
Cross polarization attenuation	0 dB
Transmitter frequency	850 MHz
EIRP	−14 dBW
RF Parameters at a Typical Receiver	**Values/Description**
Antenna pattern	omnidirectional isotropic
Antenna height	2 m
Antenna polarization	horizontal
Cross polarization attenuation	15 dB
Mobile type	cellular

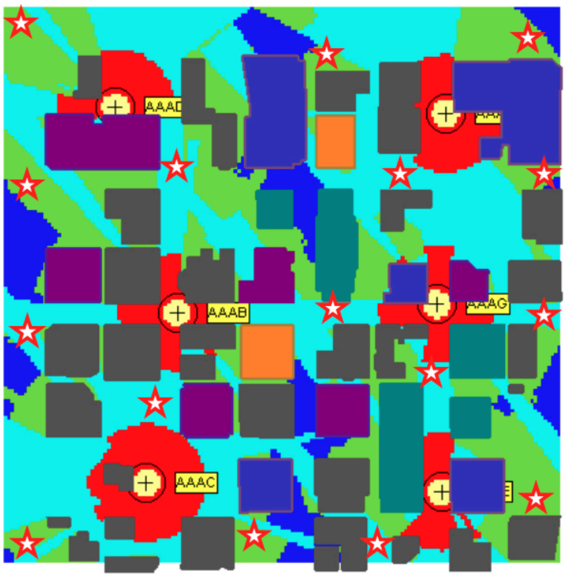
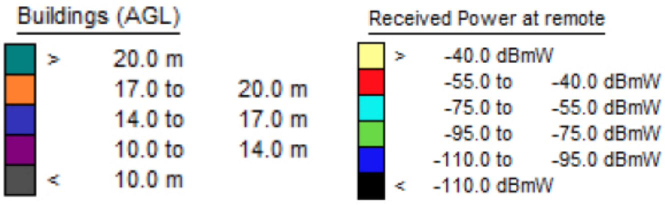


Figure 8. Wireless outdoor microcells with six candidate antenna positions and required coverage areas.



(a) (b)

Figure 9. Colour range: (**a**) building height; (**b**) received power at remote outdoor.

With regard to different antenna configurations, Figures 10–12 plots the optimal locations for outdoor microcells using SISO, MISO and MIMO antennas, respectively. It can be observed that only four cell sites are necessary to meet the target minimum received power, $P(x_{e_m}, y_{e_m}) \geq -95$ dBm, $\forall m = 1, 2, \ldots, 16$, at the marked areas in Figure 8. This means that one third of the installation and maintenance costs as well as one third of the energy consumption can be saved when compared to the case of employing all six antennas, which accordingly validates the effectiveness of the proposed BSCP algorithm in reducing the waste of resources caused by overlapping coverage areas. In addition, the coverage area when employing MIMO in Figure 12 is shown to be the largest compared to the scenarios of MISO in Figure 11 and SISO in Figure 10. For instance, the radii of the areas having a received power in the range of $[-55, -40]$ dBm with the SISO, MISO and MIMO are 52.4 m, 69.75 m and 92.21 m, respectively. Again, this observation is shown to be consistent with those observed in the indoor scenario with multiple-antenna deployment.

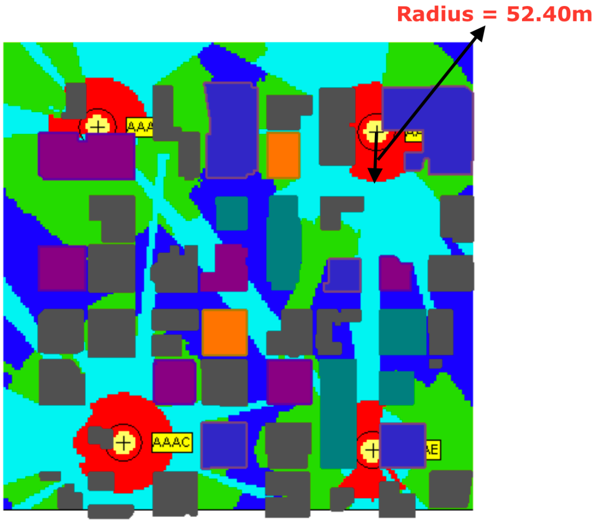


Figure 10. Heuristic site location for outdoor with SISO antennas.

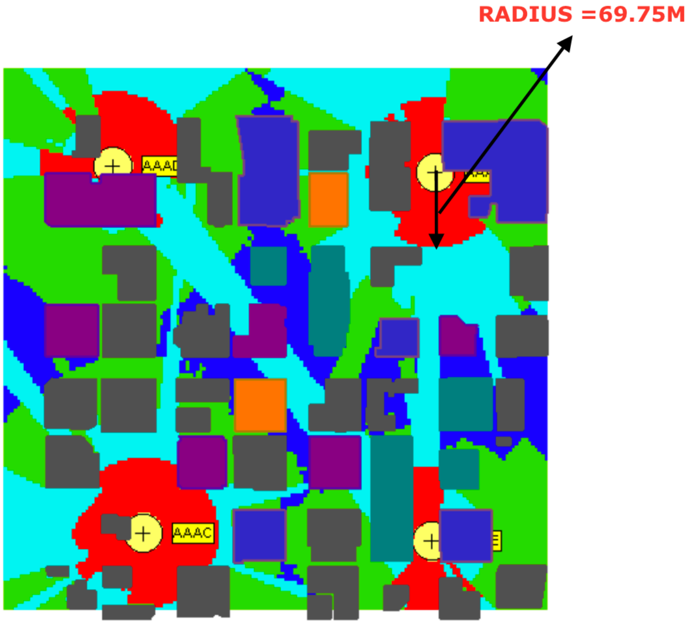


Figure 11. Heuristic site location for outdoor with MISO antennas.

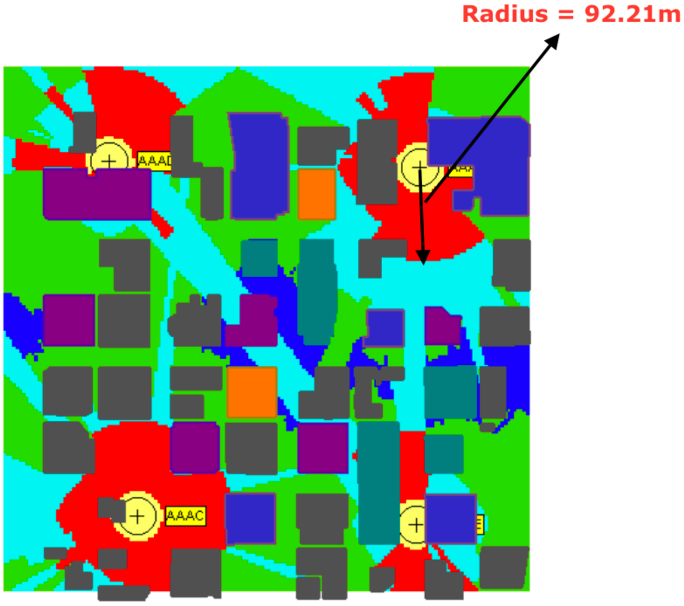


Figure 12. Heuristic site location for outdoor with MIMO antennas.

6. Conclusions

In this paper, a BSCP algorithm has been proposed for cell planning in WIOMs to find the optimal number of cell sites subject to QoS requirements of received power at remote units. A significant resource can be saved with the BSCP in terms of the number of cell sites. The BSCP algorithm has also been shown to require a much lower computational complexity compared to the conventional ESCP approach, especially when the number of candidate locations for cell sites is large.

In particular, the effectiveness of the BSCP has been validated through EDX SignalPro where both indoor and outdoor environments with different antenna configurations are taken into account. Specifically, one third of the resources can be saved when compared to the case of employing all available cell sites, which accordingly validates the effectiveness of the proposed BSCP algorithm in reducing the waste of resources caused by overlapping coverage areas. This indeed indicates a considerable saving in installation and maintenance costs as well as the energy consumption.

The proposed approach for network optimisation in this work can be regarded as an applied method for the network design and planning in practice. For future work, a stochastic geometry approach will be investigated for modelling and analysing the WIOMs, which allows us to provide analytically tractable solution for the proposed cell optimisation problem. In addition, we will investigate the usage of different simulation tools, such as NS2 or NS3, to validate the effectiveness of the proposed BSCP algorithm in terms of both network coverage and capacity.

Acknowledgments: The authors would like to thank the anonymous reviewers for their valuable comments and suggestions to improve the quality of the paper.

Author Contributions: Adeola Omorinoye and Quoc-Tuan Vien conceived and designed the experiments; Adeola Omorinoye performed the simulation, collected and analysed data; Quoc-Tuan Vien designed the mathematical model, proposed the method, and summarised the data; Adeola Omorinoye and Quoc-Tuan Vien wrote the paper. Both authors have read and approved the final manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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