Investigation of Indoor Wireless Communication Environment Using Abstract Modelling

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Modern wireless communications are realized to a large extent in closed environments. A serious problem for broadband wireless exchange of data in such an environment is the poor quality of signal transmission due to walls and other barriers, generally called blockages. The simulation of such a complex environment can be accomplished using abstract modelling of enclosed spaces and the deployment of the blockages can be on a random or deterministic principle. In this work, through abstract modelling, the quality of the communication environment in indoor areas is studied in four defined scenarios, with the aim of covering the possible situations of a real working environment to the fullest extent. The average attenuation at a fixed number of transmitters and a changing number of receivers situated randomly in the space is studied. The influence of the number of receiver units on the average performance of the wireless network in an indoor environment is shown for each of the specified four scenarios. The validity of the simulations is confirmed by verification using analytical calculations of the signal-to-interference ratio (SIR).

Голяма част от съвременните безжични комуникации се реализират в затворена среда. Сериозен проблем при широколентов безжичен обмен на данни в такава среда е влошеното качество при предаване на сигналите поради наличието на стени и други прегради, най-общо наричани препятствия. Симулирането на такава сложна среда става чрез абстрактно моделиране на затворени пространства, като разполагането на препятствията може да бъде на случаен или на детерминиран принцип. Посредством имитационно моделиране, в настоящата работа е изследвано качеството на комуникационната среда в затворени пространства при обосновано дефинирани четири сценария, целта на които е в максимална степен да покрият възможните ситуации в реална работна среда. Изследвано е средното затихване при фиксиран брой предавателни устройства и варираща брой потребители, ситуирани в пространството на случаен принцип. За всеки от четирите сценария е показано влиянието на броя приемни устройства върху средната производителност на безжичната мрежа в затворена среда. Достоверността на резултатите от симулациите е потвърдена чрез верификация с аналитични изчисления за отношението сигнал към интерференция.

Introduction

It is expected that the telecommunications networks of the future will meet the growing demands of users. The key direction of research is aimed at minimising latency, reaching higher data rates in different kinds of environments, and also at providing an opportunity to use ultra-high reliability and availability mobile connections. Current wireless networks have reached the limits of their capabilities, especially in regards to network capacity, coverage of cell-edge users, energy efficiency, quality of services (QoS), etc. [1]. There are two possible solutions – to introduce new technologies or to focus on the investigation of signal propagation characteristics in realistically modelled environments [2].

A substantial problem in telecommunications over the past few decades has been interference mitigation. Engineers have to find a way for every user to receive an excellent experience using mobile services, especially those located indoors. Nowadays, a significant amount of data traffic is generated and consumed in indoor environments [3]. The outer walls of the buildings are blockages for the signals, so the quality of service becomes really poor. The easiest approach to solving this problem is to provide small cells (access points) directly in the buildings. Hence, the coverage and capacity are improved since femtocells are located very close to the indoor users, thus reducing the loss of the signal inside the building. Also, the walls separating the rooms may limit the interference within the building, resulting in perfect coverage and excellent data rates.

Large-scale blockages such as buildings, walls etc. are often overlooked when urban cellular networks are designed. The models of blockages are often excessively simplified and their impact on signal propagation in indoor environments is not taken into account. The attenuation due to walls may become severe when the system operates in very high frequencies, such as millimetre-wave cellular networks.

Traditionally, the effects of signal propagation through walls are integrated directly into the shadowing model, along with diffraction, reflections and scattering. Regrettably this approach is very conservative and limited because it doesn't take into account the number and length of the walls, or the distance-dependence of blockage effects [4].

The shortcoming of the majority of the proposed analytical models of blockages is that they disregard the specifics of the signal propagation environment, such as the exact location of the blockages and their spatial orientation [5].

In [6] two abstract models for realistic indoor environment design are introduced and the performance of indoor users is studied. The models use blockages to illustrate the idea of walls in a building. The mathematical bedding used to develop the models is a random object process.

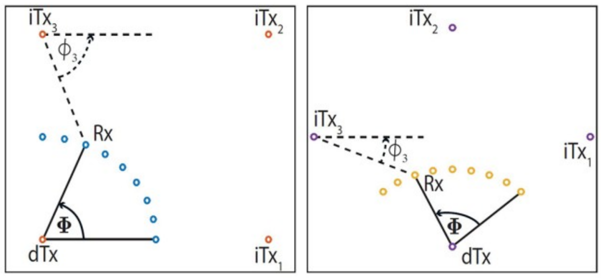
In this work the throughput of indoor users will be investigated via a simulation set with four transmitters; two different types of wall pattern; with the fixed, for each iteration. The simulations will be performed for the following different numbers of receiver positions - 5, 15, 25, 35 and 45. The model of the indoor environment will be determined by the length, attenuation and density of the walls (blockages).

System model description

Transmitters and receivers location

The four *transmitters* (*Tx*) in the indoor system model are located in the vertices of a square with side-length *R*, marked as **[square]** in the scenarios descriptions (Fig.1a). When the **[square]** transmitters are rotated by π/4, the alternative transmitters' disposal is obtained. It is labelled as **[rhomboid]** and is shown in Fig.1b. If the simulations are done without blockages, the location of the transmitters does not significantly affect the throughput of the receivers.

The *receivers* (*Rx*) (*users*) are located at the cell edge, at a distance of *R*/2 from the closest *transmitter* (*dTx*). The other three transmitters are assumed to be *sources of interference* ($iTx_{1÷3}$). The location of each receiver is determined by its polar coordinates (*R*/2, Φ), measured against the nearest transmitter. The angle Φ ranges from 0 to π /2 (Fig. 1).



Transmitter setup - **[binary]** case　　Transmitter setup - **[regular]**

(*a*)　　(*b*)

Fig.1. Transmitters and receivers positions used in the definition of the four scenarios [6]

Signal propagation characteristics

The downlink signal is assumed to suffer attenuation due to the wall blockages, distance-dependent path loss and small-scale fading. The *path loss law* is defined by the equation:

$$l(d) = \frac{1}{c} d^{-\alpha}, \qquad (1)$$

where *d* is the distance between a transmitter and a receiver; *c* is a constant equal to 38.46 dB when using femtocells; and α is the path loss exponent with a value of 2 [7].

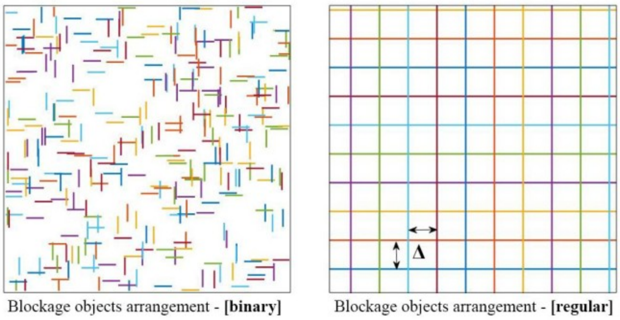
The attenuation caused by the walls is determined by accumulating the attenuation of each wall. In the models considered in this work, the blockages are defined as two-dimensional objects, and the investigated wireless network is designed to be interference limited.

Definition and distribution of blockages

In this work, two methods for wall arrangement are used. The first one is based on a Boolean scheme, where the positions of the centre points of the walls are randomly distributed according to a *Poisson Point Process* (*PPP*) of *density* λ. The lengths of the walls follow *Arbitrary Distribution* $f_L(l)$.

A wall's spatial orientation, identified by the angle θ, can be uniformly distributed in the interval [0, 2π), but this is proved to be not realistic enough [8] and will not be considered in this paper. The wall pattern, when θ is a binary choice – {0; π/2}, is denoted as **[binary]** (Fig. 2a). Wall configuration, named **[regular]**, is generated as a Manhattan grid (Fig.2b). The space between every two adjacent parallel walls is set to Δ. This distance is calculated based on the dimensions of the considered region of interest and is related to the *average wall length* $E[L]$ and *wall density parameter* λ: $\Delta=2/\lambda E[L]$. Geometrically, the region of interest is a square with side length – integer, multiple of Δ.

In order to achieve different modifications of the **[regular]** wall layout, it might be randomly shifted by δ_x in x-axis and by δ_y in y-axis.



(a) (b)

Fig.2. Generated wall maps for (a) **[binary]** *and* (b) **[regular]** *cases*

Naturally, the experiments in this work are conducted under the same conditions - the number of walls, receivers and transmitters remain constant for each simulation.

Scenarios setups

Regarding the location of the transmitters and walls layouts, the following four scenarios are defined:

S1={[binary], [square]}
S2={[binary], [rhomboid]}
S3={[regular], [square]}
S4={[regular], [rhomboid]}

Each scenario is simulated for different numbers of receivers - 5, 15, 25, 35, 45.

Analytical model

One of the most important parameters is the *average number of blockages* $E[K]$ that obstruct the path between the transmitter and the receiver:

(2) $$E[K]=\beta d\,.$$

β is *blockage factor* that differs according to the wall distribution method and for the **[binary]** case is:

(3) $$\beta=\lambda E[L]\,\frac{\left(|\sin(\phi)|+|\cos(\phi)|\right)}{2}\,.$$

ϕ denotes the *angle of the link between transmitter and receiver* against the x-axis.

Using the equations (2) and (3), the average number of blockages $E[K]$ along a link with length d – for **[binary]** case can be expressed as:

(4) $$E[K]=\lambda E[L]d\,\frac{\left(|\sin(\phi)|+|\cos(\phi)|\right)}{2}\,.$$

It is clear that the average number of blockages $E[K]$ located between a transmitter and a receiver is directly proportional to the *average length of these wall objects* $E[L]$.

For the **[regular]** case $E[K]$ is calculated as:

(5) $$E[K]=N_x+N_y+p_x+p_y\,,$$

where N_x and N_y denote the number of walls without random shifts δ_x or δ_y, p_x and p_y are the numbers of additional walls (the new walls, required to preserve the average wall density, after a random shifting is performed).

When the number of the walls is set to K_i, the *total attenuation* of the signals in this area will be $\omega_i=\omega^{K_i}$. Although each wall may have a different attenuation, the experiments conducted here consider 10 dB fixed attenuation. Then the *signal-to-interference ratio* for one indoor user can be:

(6) $$\gamma=\frac{P_0h_0l(d_0)\omega_0}{\sum_{i=1}^{3}P_ih_il(d_i)\omega_i}\,,$$

where d_o is the distance between the receiver Rx and its serving transmitter dTx, P_0 is the transmit power of the serving transmitter dTx, while P_i (i = 1, 2, 3) are those of the interfering transmitters iTx_1, iTx_2 and iTx_3, respectively. h_0 and h_i denote the small-scale fading, d_i is the distance between the receiver and the i-th interference transmitter and $l(d_0)$ and $l(d_i)$ are the path losses.

In [6] an expression to approximate *geomean* (γ) for **[binary]** case is derived. The average SIR is calculated by:

(7)

$$geomean(\gamma)\approx\int_{-\infty}^{\infty}\left(\frac{d}{d\delta}\left(1-\prod_{i=1}^{3}\frac{1}{1+\delta\,\dfrac{\omega_i'}{\omega_o}\,\dfrac{l(d_i)}{l(d_o)}}\right)\Bigg|_{\delta=t}\right)t\,dt$$

,

where $\overline{\omega}_i'$ provides an accurate approximation for *geomean* (ω_i) and is called *effective wall attenuation*.

Simulations and experimental results

Despite the location of the transmitters **[square]** or **[rhomboid]**, they are spaced from each other at a distance of R=40m. Each transmitter signifies a femtocell with a transmit power of 100 mW. The distance between the serving transmitter *dTx* and the receivers is set to 20 m. The wall density is λ=0.05 m^{-2}, and the average wall length is $E[L]$=5m. All parameters and their values are given in Table 1.

Table 1

Parameters and their numerical values

Parameter	Value
Inter transmitter distance	R=40 m
Number of interferers	3
Distance between *Tx* and *Rx* (radius)	$R/2$=20 m
Rx positions	5,15,25,35,45
Wall density	λ=0.05 m^{-2}
Wall attenuation	10 dB
Average wall length	$E[L]$=5m
Scenario realisations	10^5
Pathloss law	$l(d)=10^{-38.46/10}d^{-\alpha}$
Transmitter power (femtocells)	P=100 mW

Only for the **[binary]** wall distribution can the average wall attenuation and signal-to-interference ratio be analytically calculated (7). The **[regular]** wall pattern scenarios cannot be examined analytically but only via simulations. Vienna LTE-A system level simulator [9] is a proper tool for an abstract modelling of all the scenarios. The users' throughput results are obtained after 500 simulation runs – each with 200 identical transmission time intervals. The results for wall attenuation are obtained from 5000 simulations.

In general, in this work are presented analytical and simulation results for average wall attenuation, and system-level simulation results, evaluating the SIR and average users' throughput.

In Fig. 3 and Fig. 4 are shown graphs of wall attenuation for the four defined scenarios. The **[binary]** scenarios (**S1** and **S2**) are analytically verified as well (7), and it is clear that analytical and simulation curves overlap perfectly.

Fig. 5 shows the SIR simulation results for all four scenarios. It is obvious that the **[regular]** wall arrangements (scenarios **S3** and **S4**) achieve a higher level of SIR. The main reason is the protection offered by the walls against the interference - in every simulation run there are blockages between the users and the three interfering transmitters. On the other hand, in **[binary]** cases (scenarios **S1** and **S2**), it is more likely walls between the receiver and the interfering transmitters to miss.

The lower SIR in scenarios **S1** and **S2** can be explained by the usage of a stochastic method for distribution of the walls – it is more difficult to predict the position of blockages in **[binary]** compared to **[regular]** case.

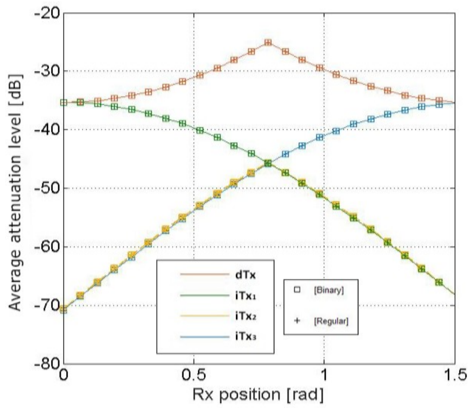


Fig.3. Average attenuation level per transmitter **S2=[*binary, rhomboid*]** *and* **S4=[*regular, rhomboid*]** *scenarios*

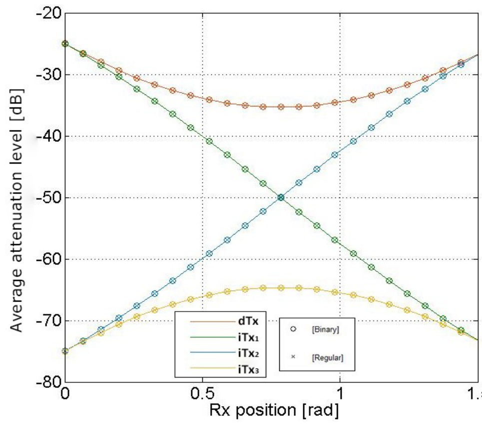


Fig.4. Average attenuation level per transmitter for **S1=[*binary, square*]** *and* **S3=[*regular, square*]** *scenarios*

When **S3** and **S4** scenarios are performed, the increase of the wall density parameter λ will lead to the suppression of the interference as well as the signal, which will result not only in degradation of the service but also in lower throughput.

Fig. 6, 7, 8, 9 and 10 depict the throughput of the users when different numbers of *Rx* positions are used - respectively 5, 15, 25, 35, 45.

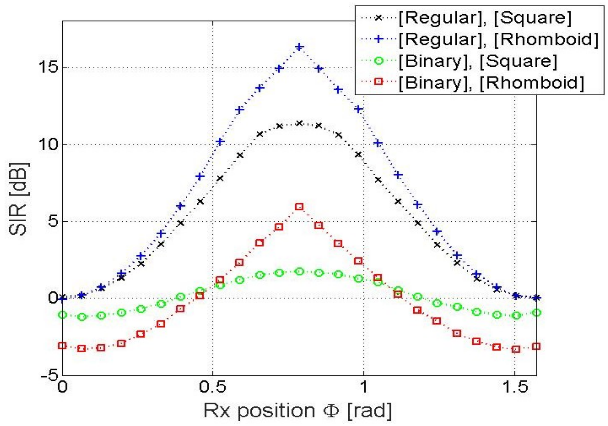


Fig.5. SIR from system level simulations for all the scenarios

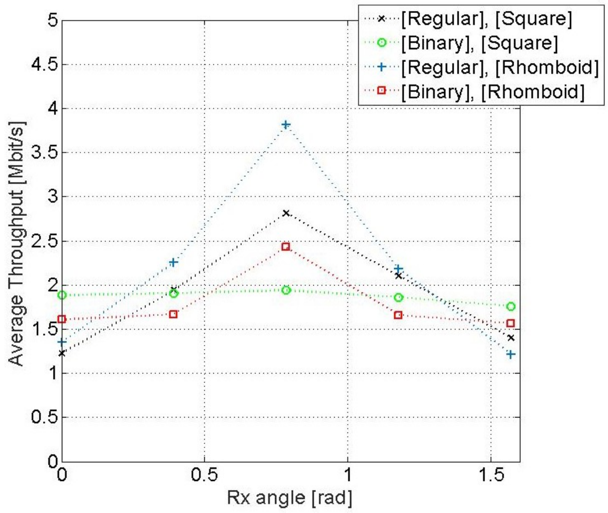


Fig.6. Average user throughput results for 5 users

Apart from the users in edge positions, the figures show the same trend as the SIR results. The Manhattan grid-like wall arrangement, denoted as **[regular]**, shows better performance compared to **[binary]** case no matter how many *Rx* positions are explored. The explanation for this behaviour is that the walls located alongside *y*-axis affect to a much lesser extent the signal propagation between the *dTx* and the users. These walls, however, are very important to suppress the interference from other transmitters ($iTx_{1\div 3}$).

For scenarios **S2** and **S4** (the **[rhomboid]** case), the users located at Φ=π/4 have the best throughput. This is apparent also from Fig. 3 – the average attenuation level is lower for the *Rx* position determined by Φ= π/4.

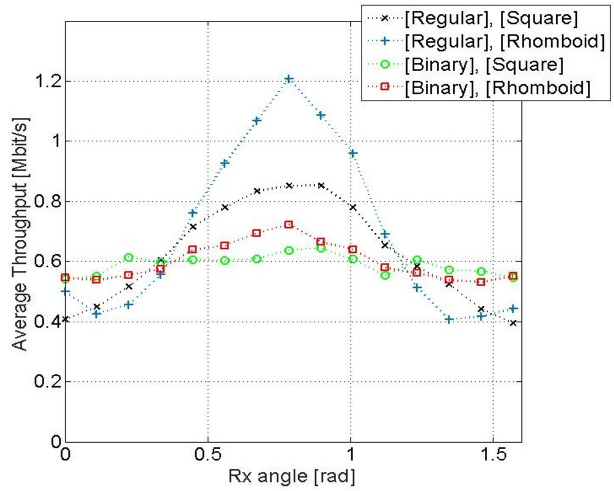


Fig.7. Average user throughput results for 15 users

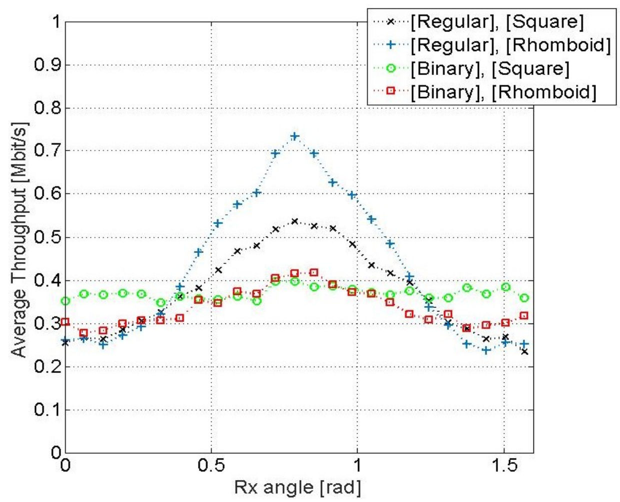


Fig.8. Average user throughput results for 25 users

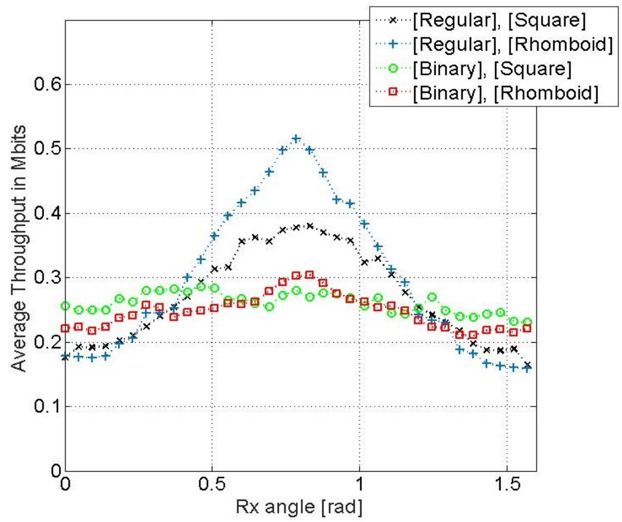


Fig.9. Average user throughput results for 35 users

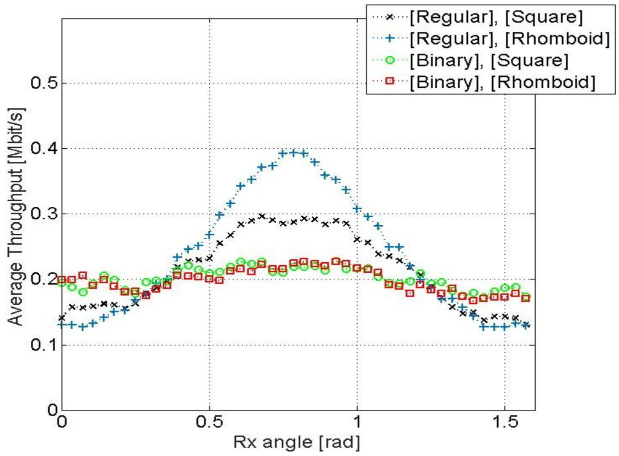


Fig.10. Average user throughput results for 45 users

Conclusion

In this paper the influence of different numbers of edge users on the average throughput in an indoor environment, using the four scenarios above determined by wall layout and transmitter location, was discussed. The results obtained by system level simulations for average user throughput show the same trend as the SIR results. The Manhattan grid (regular distribution of wall objects) shows better performance compared to the random object process based on binary arrangement of blockages. Using the same amount of physical resources in each scenario and increasing the number of users lead to a decrease in average user throughput. The peaks of the graphs indicate better performance for the users located at $\Phi=\pi/4$, which become less noticeable when the number of *Rx* positions increases. As the number of simulations increases, the smoother the curves become while the trend remains the same.

The models for distribution of walls can be used to achieve more realistic indoor environments in order to test different techniques for interference mitigation. Particularly in the **[regular]** wall arrangement, the distance between the walls may vary, thus representing larger varieties of accurate floor plans.

Future work may focus on modelling of reflections of the signal in an indoor environment, where the walls have different attenuation. It would also be interesting to investigate scenarios providing more realistically located blockages and interfering transmitters, which would help to reach more universal conclusions

Acknowledgements

The work was supported by the Scientific Project No.162**ПД**0011-07 of Technical University of Sofia.

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