AMERICAN UNIVERSITY OF BEIRUT

A FRAMEWORK FOR MOBILE RELAY NODE SELECTION FOR SERVING LTE CELL EDGE USERS

by
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AN ABSTRACT OF THE THESIS OF

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Relaying has received a big interest in wireless communication community and standardization bodies. It is meant to improve the cell edge coverage and performance through extending the reach of the base station. Mobile relays can offer attractive advantages over fixed relays in terms of reduced cost and their suitability to varying network connection demand, when exploiting the availability of public transportation vehicles, such as busses that roam streets at relatively low speeds. Indoor UE to MRN has been studied in the literature, it has been shown that a significant coverage gain is achieved. In this work, we have explored the use of mobile relay nodes for outdoor UE connectivity enhancement. In such a case, achieving any gain is not straightforward. We proposed a system simulation framework and identified cases of relay distribution where the use of mobile relays can be beneficial. Two UE-relay association strategies have been proposed an evaluated considering interference scenario. We have concluded that for a network operator, provided relays' and UEs' positions are known, operator can achieve a significant gain by enabling mobile relaying using relays relatively close to UEs with a reduced signaling overhead.

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ABBREVIATIONS

3GPP	The Third Generation Partnership Project
BS	Base Station
CCRS	Coordinated and Cooperative Relay Systems
CDF	Cumulative Distribution Function
CQI	Channel Quality Indicator
COMP	Coordinated Multi-Pint
eNB	Evolved eNodeB
GPS	Global Positioning System
LTE	Long Term Evolution
MCS	Modulation Coding Scheme
MRN	Mobile Relay Node
QoS	Quality of Service
RB	Resource Block
RN	Relay Node
RRC	Radio Resource Control
RSU	Road Side Units
SINR	Signal to Interference Noise Ratio
SNR	Signal to Noise Ratio
UE	User Equipment
VANETS	Vehicular Ad hoc Networks

CHAPTER I

INTRODUCTION

A. Motivation

The use of wireless mobile networks kept evolving during the last decades. New use cases are appearing adding new targets and challenges facing network operators and network providers. Traffic demand moved in the last decade from classic voice service to data services. Today we are observing massive data usage and trends are going toward more data consumption while new concepts like Internet of Things are becoming a reality. Any object “Thing” is expected to be reliably connected, from classic smartphone users, to machines, robots, cars, autonomous cars, integrated sensors, meters etc. All these connected things need to receive control commands and transmit data with variable volume and levels of criticality. Lot of efforts have been made to cope with this increased demand by introducing new features and spectrum chunks enabling mobile networks to support high demanding applications. In the sequel, we will focus cell edge coverage (e.g. LTE) knowing that the same concepts which will be considered can also be useful in other systems.

Considering the usual cellular deployment, all the above use cases have a common limitation: cell edge coverage. When a user gets far from its serving base station it experiences a poor signal power consequently a low data throughput with the possibility of service outage. Network operators are interested in solutions to provide fair service independently of geographic location and minimizing disparities between cell center and cell edge users. They also must fulfill regulatory requirements in terms of coverage and throughput which makes this problem of big importance. This makes low cost alternatives such as relaying very attractive for cell edge coverage enhancement. The use of relay nodes has been studied and identified as a potential solution for cell edge coverage/throughput enhancement and many papers have addressed the problem. Based on proposal from operators and other stakeholders the 3rd Generation Partnership Project (3GPP) standardization body has studied and defined to increase capacity and serve cell-edge users. Coordinated multi-point (CoMP) has been introduced. CoMP is based on transmission / reception coordination between geographically separated base station sites to enhance the system performance and end-user quality of service. Moreover, relaying has been a promising solution comprising lower-power nodes known as RN, overlaid under the coverage area of a macro-cell. From efficiency point of view, this is particularly interesting when relays can reuse frequency resources with low cost deployment.

The deployment of relay nodes reduces UE-infrastructure distance and reduces network cost as operators may avoid sites densification which is known to be a large component of the total cost. Macro cell base station and fixed relay nodes may provide bad coverage in some areas due to some geographical limitations especially in cities. In such cases, introducing mobile relays nodes can be particularly helpful. A relay can be mounted on top of a vehicle (e.g bus, train, etc.), to provide coverage within the moving vehicle. It connects with the donor eNB via relay link and connects to the UEs within the vehicle via access link [1].

Fixed Relay Node has been considered in 3GPP LTE-A till Release 10 and MRN might be proposed in next releases and has also been investigated in ARTIST4G project [2]. The MRN is intended to form its own cell inside the vehicle in which it is installed, thus giving the mother eNB (eNB to which the mobile relay is attached) the advantages of improving the coverage, enhancing the average user throughput especially at the cell-edge, and so the system capacity. Previous studies have shown that the MRN technology reduces the signaling overhead by performing group handover instead of individual handover.

The above approach of using MRNs is intended to serve users which are inside vehicles, and specifically relatively large vehicles like busses and trains. In other words, the approach is suited to scenarios in which the MRN and the users move together and remain very close to each other. In such case, the link between MRN and a UE is likely to be quasi-static and of good quality thanks to the short distance separating them. A set of users who are subject to group mobility can thus experience better quality of service with a low signaling cost. They can also see their devices' power autonomy increased while this is not a real limitation for a vehicle.

The use of MRN to serve indoor (In-vehicle) users was proven to be beneficial, however this is not straight forward. Is relaying extended to outdoor (Out-of-vehicle) users? The purpose of this work is to determine whether the use of mobile relaying can be extended to improve outdoor users' experience and specifically the users on cell edge. In subsectionB. , we summarize previous studies related to fixed mobile nodes, and mobile relay nodes serving mostly indoor (in-vehicle) users.

B. Related work

The use of MRNs was motivated by considering an interference-limited scenario [3], in which MRNs operate at a much lower transmission power as compared to macro eNBs. Both half-duplex and full duplex MRNs were considered. It was reported that the cell-edge performance while using MRNs is better when compared to the performance where UE devices are served directly by macro eNBs [3]. The performance improvement is due to the better propagation conditions provided by the backhaul link (link between the eNBs and the relays) as contrasted to the direct links between the macro eNBs and the UEs at the extremity of the cell [3].

Since the relays are characterized by low transmission power, their coverage areas are relatively small. To improve the relay performance, a solution was proposed in [4] by introducing a bias to cell selection and handover thresholds. When the bias is applied, the relay cells can be extended and an appropriate load balance is achieved. Consequently, more users will connect to the Relay Nodes (RNs).

The relay acts like an eNB from the UE’s point of view but still controlled by the eNB. Without relaying, the only handover that is required is the one from one eNB to another. However, when relays are introduced [5], there is now a handover between the eNB and the RN, and possibly between multiple RNs. In [5], the handover between the relays is a point of interest since an MRN serving static or a slow-moving UE (outside the MRN’s vehicle) requires a dynamic UE-MRN association. The handover scenario treated in [5] is based on the measurements sent from the UE to the mother eNB (which controls the RN that is serving the UE), where the mother eNB decides when to trigger a handover. The same eNB or the target eNB commands the target RN to allocate the necessary resources for the new connection. The eNB sends a handover command to the UE via the RN causing the UE to detach from the source RN and start synchronizing with the target RN. Meanwhile, packets that are in flight destined to this UE are buffered at the eNB until the handover is complete.

In Vehicular Ad hoc Networks (VANETs), the Road Side Units (RSUs) are proposed in [6] as message routers. With the information, they hear from vehicles in their ranges, the RSUs can estimate the location of a packet destination. When an RSU needs to send a packet P to a vehicle D, it is required to specify D’s current location since D is moving. For this, each vehicle sends periodically Hello packets to neighbors (including any RSUs in its coverage area) containing information about its position, speed, direction and timestamp. This enables the RSU to estimate the location of D, and hence, choose the best carrier of P. This way, the packet is forwarded from a vehicle to another until it reaches the destination.

An important notion of Coordinated and Cooperative Relay Systems (CCRS) is proposed in [5], where the CCRS system is introduced to provide enhanced cellular coverage in highly populated public transportation. The paper describes two architecture alternatives for effective realization of CCRS. One is based on the idea of interconnecting individual RNs deployed together to cooperate and share the capacity of individual mobile wireless backhaul links, while the second is based on adopting a scalable RN equipped with a Distributed Antenna System (DAS). According to the results, the CCRS allows many cellular users on board of the transportation vehicle to be served, while reducing the complexity from both the UE and the network elements.

In addition, the authors of [7] have proposed a concept like the mobile femtocells stations. They have considered two scenarios: fixed femtos with mobile UEs, and Mobile femtos with mobile UEs. It was obvious in the results that adding fixed or mobile femtocells improves the performance of the UEs. However, it was shown that mobile femtos provide better performance than the fixed ones since they can reach areas that are not covered by fixed femtos. As a matter of fact, the latter scenario supports our proposed design in which a mobile relay node is meant to provide more reliable cellular coverage to cell edge users who are suffering from weak signals that are being transmitted by the macro eNB.

Other works use mobile relays for different purposes and in various scenarios. For example, in [8] a topology is presented that employs mobile idle User Equipment (UE) nodes as virtual infrastructure to enhance the cellular capacity, while also improving network coverage. The improvements in capacity and coverage are achieved by enabling cellular-controlled direct Device to Device (D2D) links to carry relayed traffic. Reported results indicate that cell edge throughput capacity improved by 150%. In [9], on the other hand, mobile relays were proposed to realize the concept of multihop cellular networks (MCNs) as an alternative to traditional cellular architectures. That work presents experimental field studies to identify the benefits of MCNs. The testbed uses cellular connectivity into the hybrid MN (mobile node that the serving base station communicates directly with), and laptops using WiFi and acting as multihop nodes (within line of sight with each other) to deliver packets to the destination MN. Additionally, GPS connectivity was used to synchronize all nodes on the path between the hybrid and destination MNs. The results showed the ability of the multihop-equipped cellular network to extend the coverage of the base station (in the experiments, from 650m to 1Km). Obviously, the limitation of such an approach is the multihop nodes (either regular UEs, or dedicated nodes) that require coordination and massive amounts of handover due to frequent disconnections because of mobility. Similarly, the work in[10] presents the benefits that mobile relays provide to the wireless infrastructure, namely extending the base station coverage and enhancing wireless connection throughput. Relay locations are modelled as realizations of a two-dimensional Poisson process with random motion. Two important performance metrics are derived for out-of-coverage end users: the probability of establishing a route, and the expected duration that a route or connection can be sustained. Using mobile relays, the results demonstrate that throughput gains can be achieved for an end user within the coverage area.

In the work presented in[11], mobile relays are used in two scenarios. In the first, a mobile relay is fitted on a bus to provide coverage in an area, while in the second, a user equipment (UE) is elected to provide relaying functionalities to other UEs. The type of relaying used depends on the layers introduced into the mobile relay: Layer 1 for mobile repeaters, and Layer 1/2/3 for moving access points. The results showed that many parameters need to be statistically monitored to extract useful information for use as input to the mobile relay algorithm selection. In another work, namely [12], the concept of the mobile Femtocell (MFemtocell) network is proposed. MFemtocells can be deployed in moving vehicles (trains, buses, or private cars) to provide enhanced user throughput, extended coverage, reduction of signaling overhead, and drop calls. Consistent with other works, simulation results demonstrated that the spectral efficiency and average user throughput can significantly be increased with the deployment of MFemtocells.

Paper [13] considers the impact of node mobility on the selection of the path from the access point to the destination node node. More specifically, the access point uses link signal to noise ratio (SNR) measurements provided by the mobile nodes to select the path, either as direct or two-hop via a mobile relay. The SNR measurement collection is based on periodic hello broadcasts. The reported results reveal that increasing nodes speed can lead to performance that is worse than transmitting directly, and that discarding old measurements can significantly improve the BER performance.

Finally, the work in[14] proposes a general analytical model for mobile relay scenarios using stochastic geometry. By applying different parameters into the model, the Cumulative Distribution Function (CDF) of the SINR and the average achievable rate on different links in both traditional mode and relay mode can be obtained. According to the numerical results, the penetration loss between outdoor and the inside of the vehicle is a key factor for deciding whether mobile relaying could bring data rate gains into the system. When the penetration loss is large, the mobile relay could bring considerable data rate gains to the UEs inside the vehicle.

C. Relaying types

There are two main relaying types that can be identified: Amplify and Forward (AF), and Decode and Forward (DF). Below, we give a brief description of each type for completeness.

Such relays, amplify the signal then forward it to the destination. This is easy to implement and has been widely used in current wireless systems.

The signals are expressed as follow:

At the relay from the source:

$$Y_r = H_r.X + \ N_s$$

At the destination, the amplified (power gain G) from the source:

$$Y_d = \sqrt{G}.H_d.Y_r + N_d$$

Where X represents the signal sent from the source, H_r is the channel gain between the source and the relay, h_d is the channel gain between the source and destination and finally, N_s and N_d represent the noise affecting the communication. Here, the relay receives the signal and forwards it to the destination as follow:

$$Y_d = \sqrt{G}.H_d H_{r.}X + \quad \underbrace{\sqrt{G}.H_d.N_s}_{noise\ amplification} \quad + N_d$$

We can see that the AF relay amplifies both the signal and the noise. Thus, a small gain can be expected from such relays.

In this case the received signal is decoded, errors caused by channel and noise are then corrected, before being re-encoded and forwarded. The message is then reconstructed to remove impairments so DF relaying doesn’t suffer from the problem of noise amplification.

$$Y'_d \ = \sqrt{G'}.H_d.Y'_r \ + N'_d$$

Where H_d is the channel gain between the source and the relay, G' represents the amplification gain, Y'_r is the signal at the source, N'_d is the noise affecting the communication and Y'_d is the signal at the destination.

In DF relaying, the overall throughput can be maximized, if both links have equal throughputs. The DF RNs outperform the AF RNs both in the cell center as well as at the cell edge, and accomplished better performance for different relay link gains [15]. In our model, we are using DF relays.

Without relay assistance, cell-edge users may suffer from bad channel conditions, leading to dramatically low throughput or even complete connection outage. From the above review, it can be concluded that mobile relay nodes are an efficient solution for cell-edge coverage improvement. This is particularly true for indoor cell-edge users who would maintain a static link with the relay, whereas direct eNB connected indoor cell-edge users will suffer from penetration loss. For outdoor cell-edge users, there is no penetration loss, but the link to the relay is not likely to be static. Whether coverage/throughput gain is achievable in such a case, it is the question that we will explore in this work.

This document is organized as follows. In section 0, a detailed system description is given where we list the main effects impacting mobile relaying. In section 0, we propose and compare UE-MRN association strategies evaluated through simulation. In section 0, we show and analyze simulations results. In section 0, we conclude this work and introduce further perspectives for cell-edge experience enhancement based on mobile relay nodes.

CHAPTER II

SYSTEM DESCRIPTION

A. System model

We consider a macro-cell deployment where vehicles will play the role of relay nodes. They are equipped with a navigation system that maps Global Positioning System (GPS) positions to road maps, to enable them to know their positions (i.e geometric coordinates), broadcast it to the UEs, and update the neighboring eNBs [16]. A simple general scenario is illustrated in **Error! Reference source not found.** , where each MRN vehicle knows its position and periodically broadcasts beacons that include positions, speeds, directions, and timestamps. This information allows UEs to know if an MRN is moving toward it or away from it. The figure depicts the current location of an MRN (MRN_k) along with its possible farthest locations (Points 2, 3, 4, and 5) before the UE disconnects from it due to exiting its transmission coverage. The transmission coverage of the MRN is illustrated using the dotted circles, and its range is depicted through the direct lines that connect the UE to it.

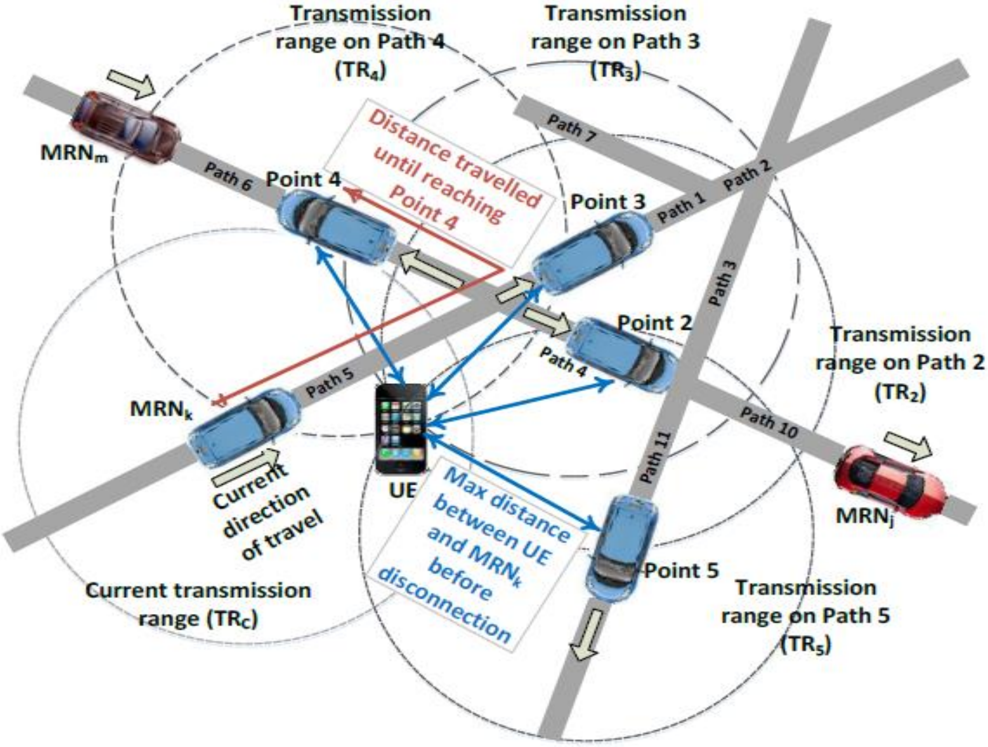

Figure 1. MRN possible paths in an area of roads showing its farthest locations before it disconnects from the UE

In our work, we can consider two metrics for the UE to be assisted by the most suitable MRN to connect with. The first is the signal-to interference noise ratio (SINR) at the UE, while the second is the expected connection lifetime. The SINR can be directly measured by the UE for nearby MRNs that are already covering it or those that are expected to cover it in the near future (i.e., by the time the UE is expected to start transmitting data). In addition, the time of staying connected (time of connection) needs to be computed. As illustrated in **Error! Reference source not found.** while moving, the MRN can change its path or direction after reaching an intersection. Depending on which road segment or segments the vehicle is driven, the time until the UE loses coverage of this MRN could vary widely. The example in the figure shows a UE that is currently being covered by MRN$_k$, and the latter is approaching an intersection. After reaching the intersection, the vehicle can take one of three possible paths, each of which results in a different time of staying-connected. As shown, after crossing Points 2, 3, and 4 on Paths 2, 3, and 4, respectively, the UE loses coverage. Moreover, if the vehicle takes Path 2 and becomes disconnected from the UE after crossing Point 2, it reconnects with the UE after crossing the second intersection and taking Path 5, but then it disconnects from the UE after reaching Point 5. Given the current location of the vehicle MRN (known to the UE with some uncertainty) and the coordinates of Points, 2, 3, 4, and 5, the UE can compute using its knowledge of the road map the driving distances to these points. Given the broadcasted speed of the MRN and the inferred average speed, the UE can translate these distances into times. Out of these estimated times, the expected time of staying-connected could be calculated and consequently associated with MRN_k. By computing the expected total time of connection of each MRN that is in proximity, the UE can now choose the most suitable one to associate with. The decision of the UE in choosing an MRN is therefore defined by SINR and minimum time thresholds to minimize the probability of disconnections. In our model, we assume that the users are mostly pedestrians, and hence their relative speed is very small when compared to those of the MRNs. We therefore consider the cell edge users to be static relatively to the MRNs. The total number of MRNs in the cell can vary between 80% and 120% of the value (28) we are using in the simulations.

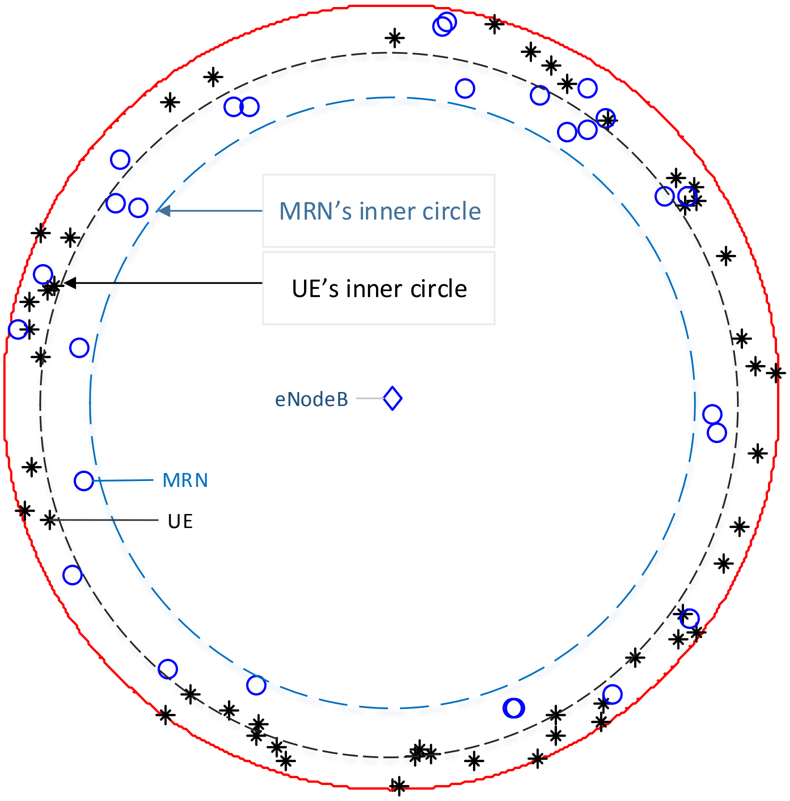

Figure 2. Illustration of UE and MRN distribution

Figure 2 illustrates the cell edge region within which UEs suffer from a poor coverage from the macro cell eNB, and therefore would need the assistance of nearby mobile relay nodes (MRNs). On the other hand, the MRNs that could assist the above UEs with cellular coverage must themselves at least have acceptable coverage from the eNB. Hence, in Figure 2, the outermost circle represents the eNB's coverage area, while the region between the two inner circles delimit the movement of the MRNs that could assist the cell edge UEs, which in turn lie between the outermost and middle circles. The MRNs are assumed to be mostly public transportation vehicles that stop frequently to pick up and drop off passengers, and hence their average movement speed is low.

The outer most circle represents eNB's coverage area while MRN (respectively UE) inner circles delimit the rings where MRNs (respectively UEs) are distributed. The

MRNs are moving at a slow velocity, which is typical for public transportation vehicles that stop frequently to pick up and drop off passengers.

B. Link budget

The received signal power at any distance *d* from a transmitter can be predicted from a link-budget, which is the inventory of all attenuations and gains incurred by the signal during transmission, propagation and reception. The downlink link budget **[17]** is given by

Equation 1

$$P_r = P_t + G_t + G_r - PL + M_{sh} - BL$$

In the above, P_r is the received signal power (in dBs) at the UE, P_t is the transmitted output power (dB) from the MRN, G_t and G_r are respectively the transmitter and receiver antenna gains (dB), PL is the path loss between the transmitter and the receiver, M_{sh} is the shadowing which is log-normal distributed, and finally *BL* is the body loss of the user holding the UE. We need to choose suitable pathloss and shadowing models, and then define the received signal level at the UE from the MRN separated by a distance *d*, using the above link budget.

C. Channel Path loss model

We choose the well-known Okumura-Hata propagation Urban Model [18] for pathloss, given by

Equation 2

$$\begin{aligned}\mathrm{PL\ (dB)} = 69.55 + 26.16\log\mathrm{f}\ - 13.82\log(\mathrm{hb}) - \mathrm{a(hm)} \\ + [44.9\ - 6.55\log(\mathrm{hb})]\log(\mathrm{d})]\end{aligned} \tag{2}$$

Where *f* is the frequency in (MHz), d is the distance (cell radius), h_b is the MRN antenna height (in meters), *hm* is the UE antenna height, and finally $a(hm)$ is defined as follows in

Equation 3

$$\mathrm{a(hm)} = [1.1\log(\mathrm{f}) - 0.7]\mathrm{hm} - [1.56\log(\mathrm{f}) - 0.8] \tag{3}$$

D. Shadowing

Slow fading (shadowing) is modeled as a log-normal distribution, which is a normal distribution in dB having a zero average. The shadowing standard deviation (σ_{sh}) depends on the propagation environment.

E. SINR

The signal-to-interference-and-noise ratio SINR is generally defined as in

$$SINR = \frac{P_r}{I + N} \tag{4}$$

Where P_r is the wanted signal power obtained from the link budget defined in Equation 1, I is the total interference power, and *N* is the thermal noise power. The received signal from the selected relay is the useful signal for a UE while the signals from other neighboring relays and cells are interfering signals (inter-cell interference), in addition to the interference power received from neighboring macro cells and MRNs in other cells. The interference power from the other MRNs in the same cell and macro-cell eNB (intra-cell interference) can be computed in a similar manner as the wanted signal (i.e., using the same parameters and propagation model) in case the relays are authorized to reuse the same frequency resources. Otherwise, there is no intra-cell interference. Whether frequency resources are reused in the same cell is an engineering choice that can be done by the operator depending on the potential gain that would be achieved. In this work, we will compare scenarios with and without intracell frequency reuse. Interference from neighboring cells and relays (inter-cell interference) is accounted for using an interference margin (IM) in the link budget. Indeed, a more accurate evaluation of inter-cell interference can be performed in a future work, using realistic network deployment.

The SINR expression measured by a user equipment served by relay R_k is noted $SINR_{UE}^{R_k}$ and can be written as follows

Equation 4

$$SINR_{UE}^{R_k} = \frac{P_{UE}^{R_k}}{N + P_{eNB-UE} + IM + \sum_{\substack{j=1, \\ j \neq k}}^{j=R} P_{UE}^{R_j}} \tag{5}$$

Where $P_{UE}^{R_k}$ is the received signal from serving relay R_k and $P_{UE}^{R_j}$ is the interfering power from other relays. The thermal noise at the receiver is a function of the assigned bandwidth and can be calculated as indicated in

Equation 5

$$N = K.T.BW \tag{6}$$

Where K is the Boltzmann constant, T is the temperature, and BW is the receiver configured bandwidth. At 290 K temperature, the thermal noise reduces to the following expression in

Equation 6

$$N\ (dBm) = -174 + 10 * log10\left(BW_{(Hz)}\right) \quad (7)$$

1. ***SINR to throughput mapping***

Resource allocation and channel bandwidth are directly related to spectrum efficiency. In our simulation we are evaluating the throughput because a mapping for SINR-throughput described in 3GPP TR 36.942 version 13.0.0 Release 13 (i.e. spectrum efficiency) is used by 3GPP RAN1 specifications [20]. Moreover, the results can be scaled to any bandwidth that can be used in other simulations.

$$Throughput\ ,Thr, \left(\frac{bps}{Hz}\right) = \alpha.S(SINR)\ \ for\ SINR_{min} < SINR < SINR_{max}$$

$$Thr = 0\ for\ SINR < \ SINR_{min}$$

$$Thr = Thr_{max}\ for\ SINR > SINR_{max}$$

Where: $S(SINR) = log_2(1 + SINR)\frac{bps}{Hz}\ and\ \alpha\ is\ the\ attenuation\ factor$

The parameters α, $SINR_{min}$ and Thr_{max} can be chosen to represent different modem implementations and link conditions. In the remaining $\alpha = 0.6$, $SINR_{min} = -10\ dB\ and\ Thr_{max} = 4.4\ bps/Hz$

CHAPTER III

UE-MRN ASSOCIATION

A. Connection duration

We use the diagram of Figure 3, which is a zoom-in of Figure 1. MRN_k is currently covering the UE and is approaching Intersection I_1, after which it will take one of three possible paths, as shown in the Figure 3**Error! Reference source not found.**. We assigned equal probabilities to the possible paths that a vehicle will take upon reaching an intersection, but in future work, we can assign probabilities that are functions of some measurements and statistics, like the average volume of traffic on each of the outgoing paths of an intersection. Such data may be obtained from the traffic authority database, or learned by Road Side Units, which normally receive beacons from passing by vehicles. On the other hand, if an MRN knows with some certainty which path it will take (learned from previous trips), it can include this information along with the other data discussed above in the messages to the UE, thus allowing the latter to associate more definite probabilities to the outgoing paths of an intersection for this MRN.

Going back to Figure 3, we assume that all MRNs have the same transmission range R, and so, when a UE needs to make an association decision, it draws a circle with itself being the center, and the radius equal to R. It then identifies the intersection points of this circle with the roads in the range. In Figure 2, these points are Points A, B, C, D, and E. They represent exist points beyond which any MRN will lose connection with this UE. Note that the intersection with the road that the MRN is currently on (i.e., Point O) is excluded since we assume that the MRN will not be making a U-turn. Using the information about the roads from the map, the UE can compute the distance to each of these points from the current MRN's location, and next compute the times of reaching these points using the MRNs' reported average speeds. Finally, the UE uses the probabilities associated with the outgoing paths of each intersection that the MRN can reach in the area, to compute a connection time. This is done for each MRN that the UE is in range with.

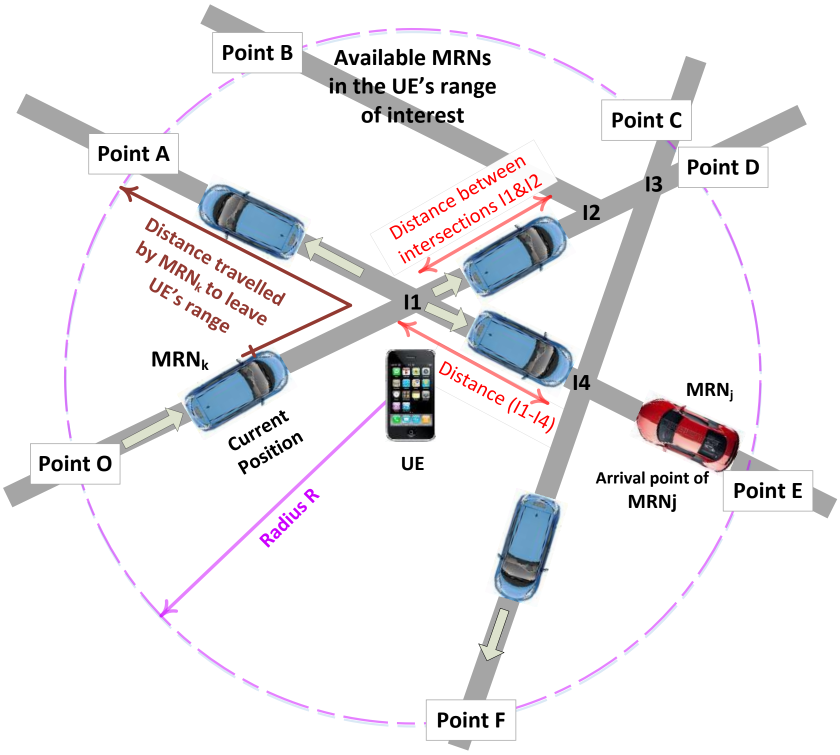

Figure 3. Representation of area of coverage around the UE

1. ***UE-MRN association strategies***

From the network operator's point of view, such a problem is addressed by optimizing the cell throughput. This involves a frequency resource allocation optimization, and is given by:

$$\mathrm{C} = \operatorname{argmax}_l \left[\sum_r^R \sum_n^N \sum_k^K BW_{R_k} \times a_{k,r} \times b_{n,k} \times c_{k,r}^l \times log_2(1 + sinr_{k,n,r}) \right] \quad (8)$$

With:

$$\sum_k^K b_{n,k} \le N \quad \text{and} \quad \sum_r^R b_{k,r} = 1$$

where $a_{k,r \in} A_{N_{UEs} \times N_{MRNs}}$, $b_{n,k \in} B_{N_{UEs} \times N_{MRNs}}$, $c_{k,r \in} C_{N_{UEs} \times N_{MRNs}}$, R is the number of relays, N Is the number of users, K is the number of resources and A and B are binary elements matrices whose nonzero elements represent UE-MRN links verifying $SINR > SINR_{threshold}$ and $Time\ of\ connection > Time_{threshold}$, respectively. On the other hand, C is the final selection matrix. The above optimizes the total cell throughput but does not guarantee fairness. In other words, we can have users who are allocated large numbers of resource blocks while other users may be starved. To obtain fairness, we choose to allocate a similar number of resource blocks to all cell-edge users.

2. ***Best SINR selection***

SINR is a commonly used metric for resource allocation and channel quality assessment. Accordingly, we first evaluate the UE-MRN association based on the best SINR measured by the UE among multiple relays. Obviously, the highest SINR reflects the best instantaneous link, but does not guarantee long connection lifetimes when the channel varies as in the case of fast fading or shadowing. This results in frequent relay re-selections and significant signaling overhead, and can have dramatic impact on UE autonomy. This MRN selection scheme can be written as follows:

$$MRN_{selected} = \underset{k \in S_0}{\operatorname{argmax}} \left[SINR_{UE-MRN_k}\right]$$

Where S_0 is the set of relays close to the UE.

3. ***Best SINR-connection duration selection***

The link between the MRN and the eNB is supposed to be sufficiently good, and an MRN is supposed to be able to serve multiple UEs, meaning it should be able to hold enough resources. Instead of using SINR alone we propose to couple the best SINR with the expected connection duration. This has the advantage of avoiding heavy signaling overhead, as was pointed out earlier. In other words, coupling SINR with the expected time allows for ensuring enough time to transfer the needed data volume to and from the UE. Accordingly, the notion of “volume based MRN selection” will be used in the remaining part of this document. The MRN selection scheme can thus be written as follows:

$$MRN_{selected} = \underset{k \in S_0}{\operatorname{argmax}} \left[Throughput(SINR_{UE-MRN_k}) \times Time\ of\ conection_{UE-MRN_k}\right]$$

where S_0 is the set of relays close to the UE having an expected time of connection higher than a given threshold defined above as $Time_{threshold}$,.

$$S_0 = \{Relays\ close\ to\ UEs\ |Time\ of\ connection_{UE-MRN} > Threshold\}$$

B. UE attach and handover procedures

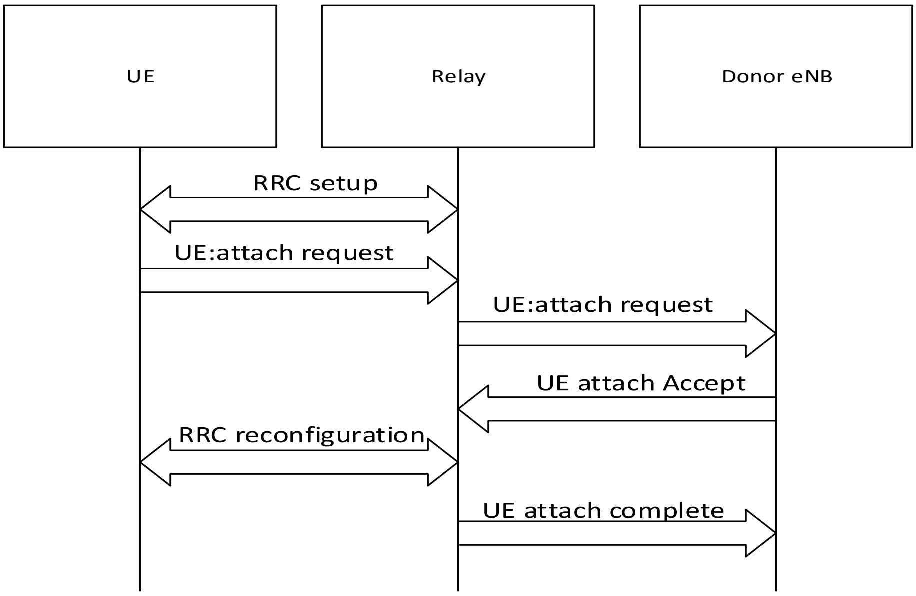

Figure 4. UE attach procedure

Error! Reference source not found. shows the UE attach procedure how the UE does its SINR and time of connection computation, sends them to UE and sends the attachment request to relay who in turn forwards the request to eNB where the acceptance is done. eNB forwards sends the acceptance to relay, UE does his radio resource control with the relay and then the attach is complete.

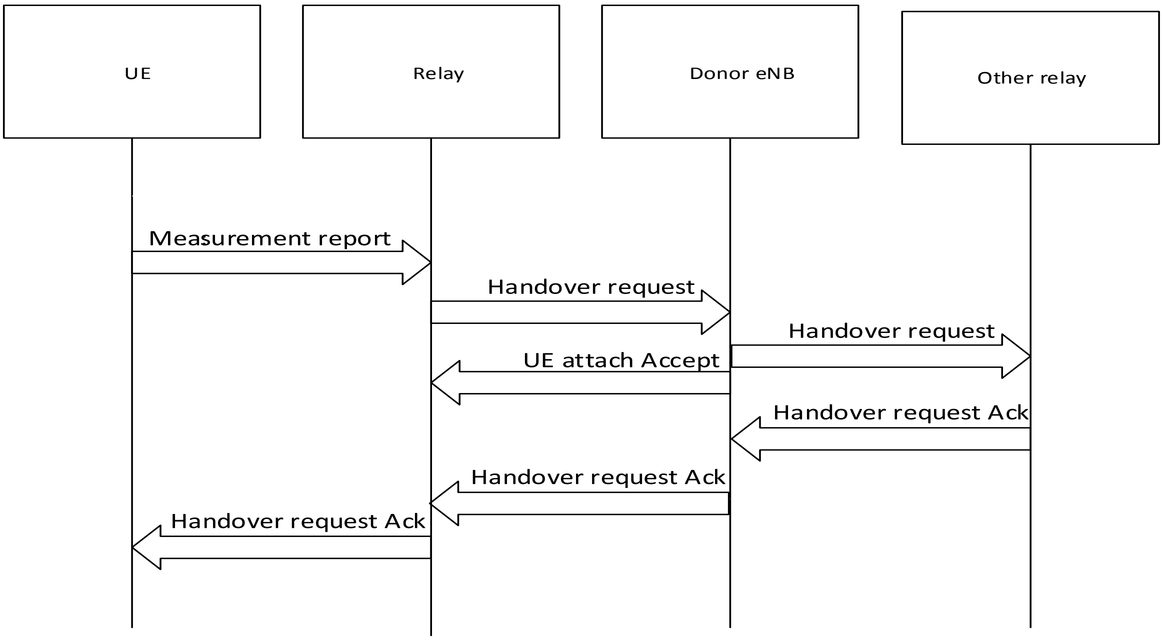

Figure 5. UE Handover procedure

Figure 5 shows the UE handover procedure after sending its measurement reports to the relay. The relay sends a handover request to the eNB who in turn sends a handover request to another candidate relay who can meet the UE needs and then a handover request acknowledgment is sent to the UE. The handover in our system is done according to each UE measurement reports and based on its needs in term of time of connection while in other papers it is done as group handover since UEs are inside vehicles.

CHAPTER IV

SIMULATION RESULTS

A. System parameters

We assume Decode and forward relaying is used thus avoiding additional noise figure in the MRN receiver. Below, we show the simulation parameters and their default values [21].

Parameters	With interference	Without intra-cell interference
eNB power (dBm)	30	40
MRN power (dBm)	23	23
Number of MRNs	28	28
Number of UEs	50	50
eNB's Cell radius (m)	1500	1500
Carrier frequency Fc (MHz)	2000	2000
Relay antenna height (m)	3	3
eNB antenna height (m)	20	20
MRN velocity km/h	30	30
Receiver thermal noise (dBm)	-107	-107
Shadowing standard deviation (dB)	8	8
Noise bandwidth (MHz)	5	5
Interference Margin IM (dB)	6	6
Number of samples	500	500
SINR threshold (dB)	-10	-10
Time threshold (s)	60	60

Table 1. Simulation parameters

The first step is to get a global idea about the configurations where a potential gain from using MRNs can be expected. The gain is evaluated using the SINR cumulative density functions (CDF) which is translated to a gain in throughput. To do so, we first explore different scenarios in terms of MRN and UE distribution within the cell. It is noted that intra-cell frequency reuse (consequently with and without intra-cell interference) is considered in all the scenarios.

When the same frequency resources are used by the MRNs and the eNB, the macro-cell eNB may outperform the MRNs due to the high interference power at the UE from the eNB, unless the macro-cell eNB used power is relatively low (e.g., 30 dBm) [21]. More specifically, reduced interference may be achieved using the two following cases:

Case 1: Intra-cell frequency reuse

The macro-cell eNB and the MRNs use the same frequency resources, but the eNB power is reduced, e.g., to 30 dBm.

Case 2: No Intra-cell frequency reuse

The frequency resources are orthogonal, consequently not reused by the MRNs and the eNB at the same time. This allows for a higher eNB power to be used.

B. Impact of MRN distribution

A key factor in this study is the distribution of the MRNs and UEs inside the cell area. Since we are looking to improve cell-edge users' experience, we only consider the UEs that are in the outer ring of the cell area (farthest 10% to 20% of the cell radius from the eNB). Moreover, we need to evaluate to what extent the MRNs can be far from the cell-edge UEs.

Error! Reference source not found. and Figure 7 **Error! Reference source not found.** show two example scenarios of MRN and UE positions in the cell area. In Figure 6 the MRNs are much farther from the UEs than in Figure 7. This is a key factor that we consider and illustrate with the help of Figure 6.Figure 7 In Error! Reference source not found., the cross-value we discussed earlier is now around ‘4 dB’. Here the MRNS and UEs are in the outer 50% and 10% of the cell area, respectively. This mean that UEs are closer to MRNs than Figure 6 This results in gain improvement when using relays.**Error! Reference source not found.**. A cell-edge users SINR gain can only be expected in case the MRNs are reasonably far from the UEs. This involves a tradeoff: As the MRNs get closer to the UEs, they become farther from the eNB, whereas if they are chosen to be very close to the cell edge, the assumption of a reliable eNB-MRN link will not hold.

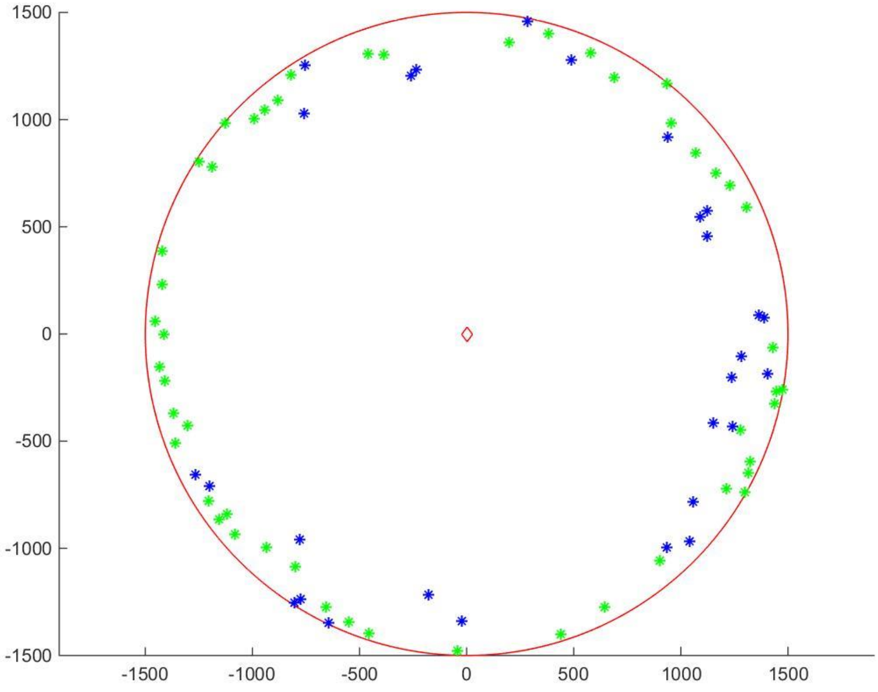

Figure 6. UE and MRN positions over the cell area where the MRNs are in the 20% of the cell area and the UEs are in the 10% of it

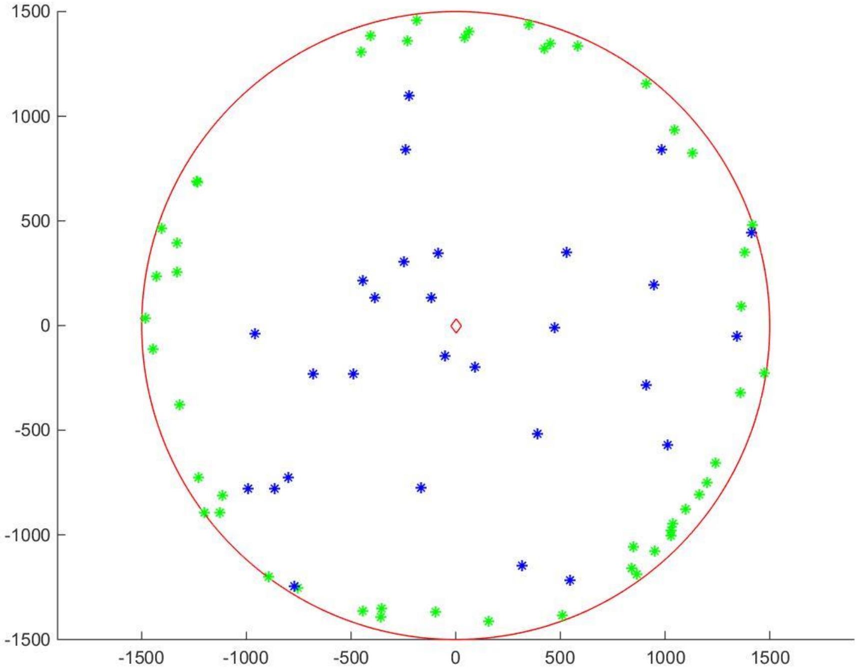

Figure 7. UE and MRN positions over the cell area where MRNs are in the 90% of the cell area, and the UEs are in the 10% part of it

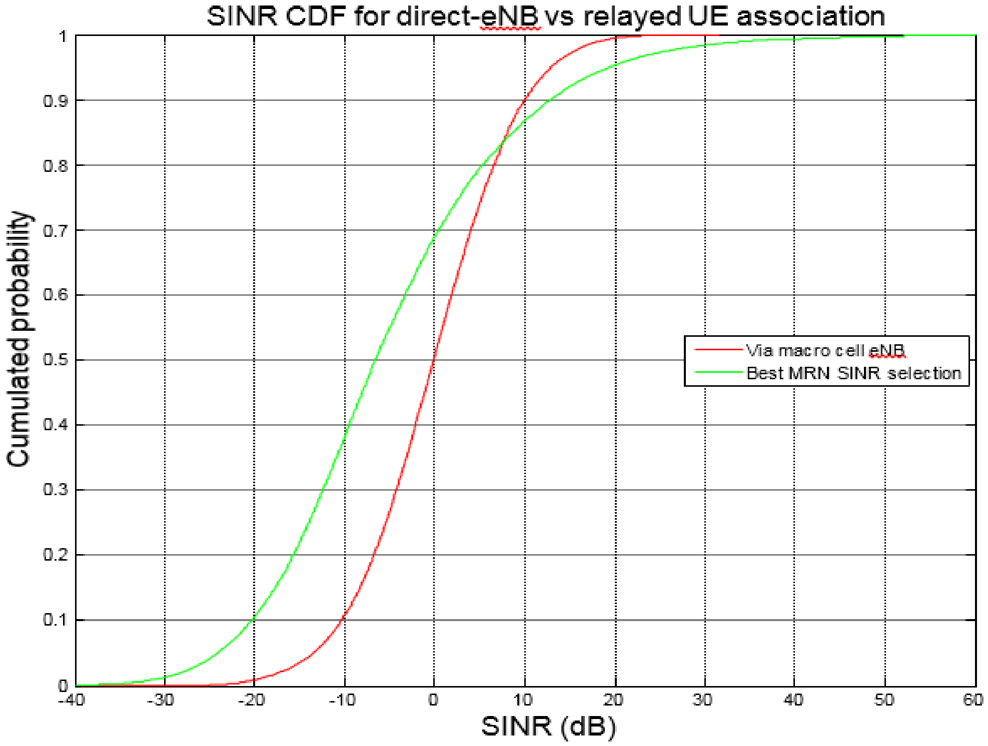

Figure 8. CDF of MRNs SINR for eNB power of 30 dBm with interference.

As shown in Figure 8 the SINR values correspond to scenario with interference. The MRNS and UEs are in the outer 90% and 10% of the cell area, respectively. For SINR ‘8 dB’ the relay assistance start to be more effective in increasing SINR value. This is due to the MRN distribution in the cell because in this case MRNs are relatively far than UEs and consequently the MRN-UE distance is close to eNB-UE distance.

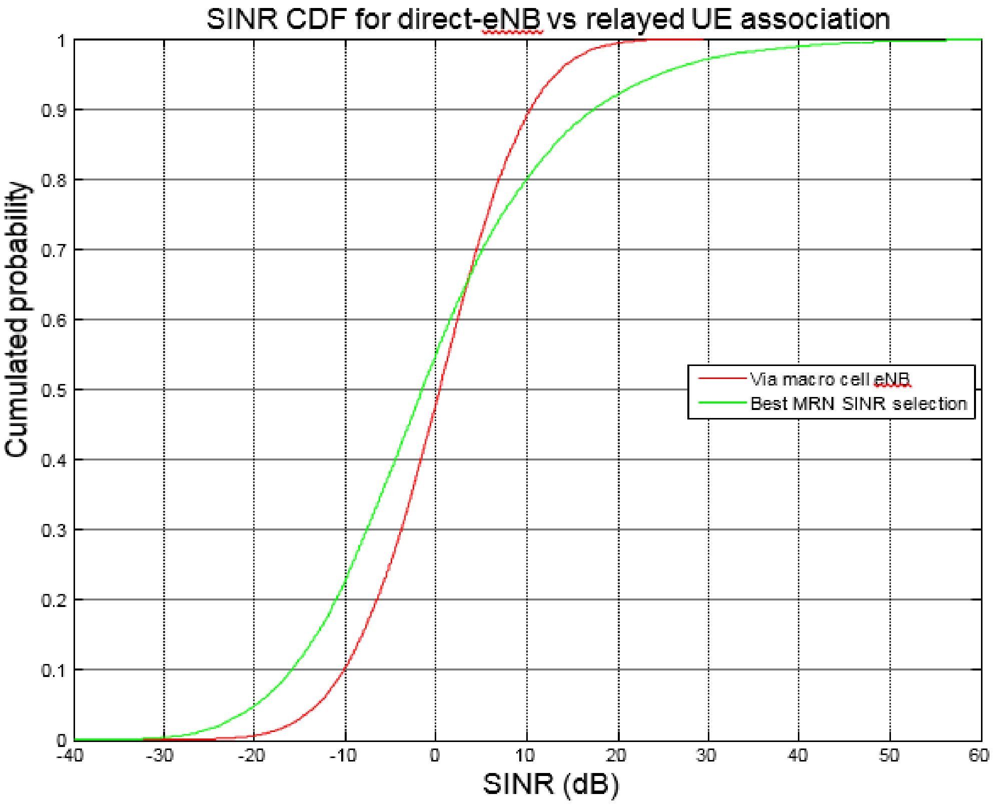

Figure 9. CDF of MRNs SINR for eNB power of 30 dBm with interference.

In **Error! Reference source not found.**, the cross-value we discussed earlier is now around ‘4 dB’. Here the MRNS and UEs are in the outer 50% and 10% of the cell area, respectively. This mean that UEs are closer to MRNs than Figure 6 This results in gain improvement when using relays.

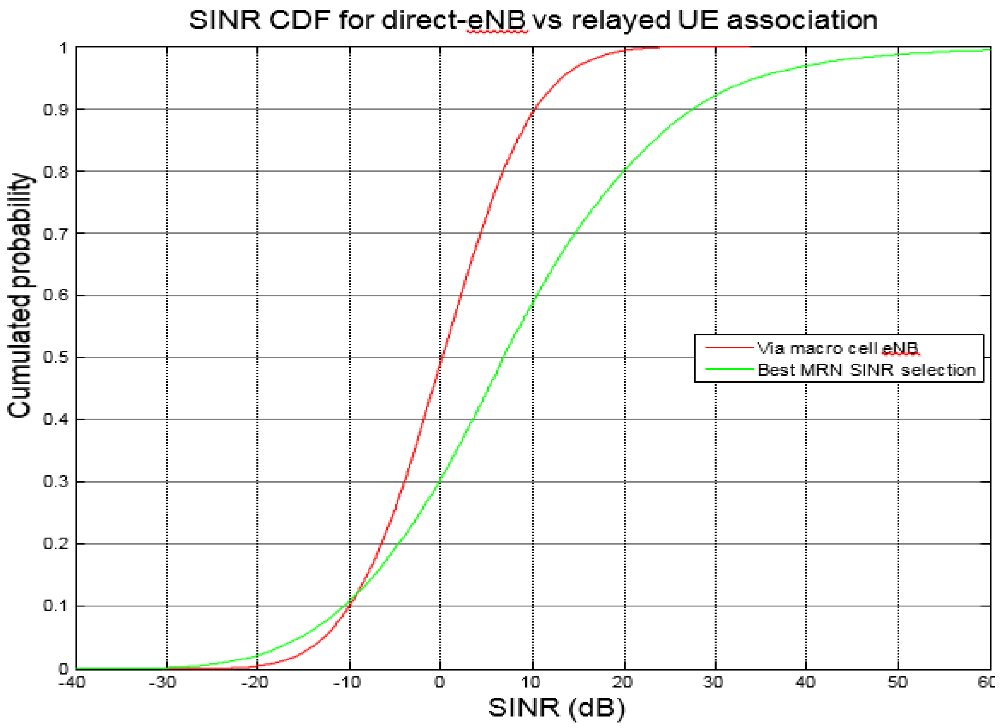

Figure 10. CDF of MRNs SINR for eNB power of 30 dBm with interference.

Figure 10 shows clearly that when The MRNS and UEs are in the outer 20% and 10% of the cell area, respectively the cross-value is lower than the above two distributions and is now '-10 dB'. This result demonstrates that as much as MRNs are closer to UEs higher SINR gain can be achieved with relay assistance

C. Performance comparison of MRN selection strategies

Concerning the MRNs distribution, we consider scenarios corresponding to the MRNs moving within the outer 20% of the cell radius. Next, the MRN selection strategies described in section **Error! Reference source not found.** are compared for both intra-cell interference scenarios.

1. ***Case 1: Intra-cell frequency reuse***

From **Error! Reference source not found.** we can see a small degradation in the SINR CDF when the "volume based selection" is used. The use of MRNs is advantageous starting from a SINR value of around -10 dB. This degradation can be explained by the fact that this selection scheme may choose an MRN that offers a lower SINR to a UE but a longer connection time, as compared to the best SINR selection scheme. In practice, such a tradeoff may be acceptable having in mind the signaling overhead reduction achieved using a longer connection time.

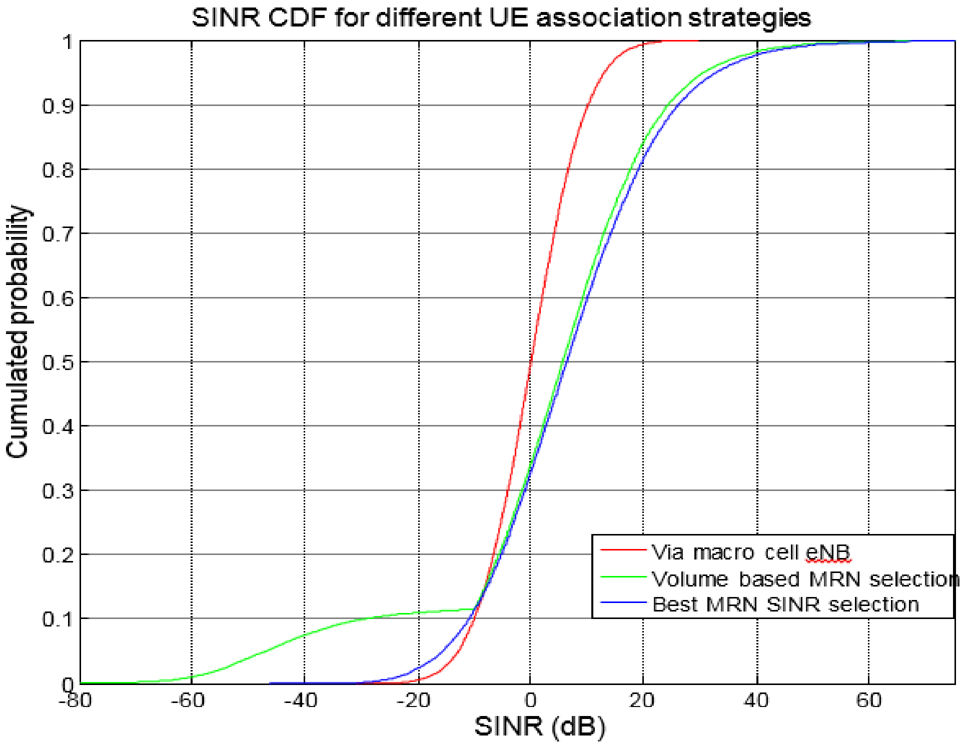

Figure 11. CDF of SINR best MRNs with interference when the eNB power is 30 dBm, and where the MRNs and the UEs are in the outer 20% and 10% of cell area, respectively.

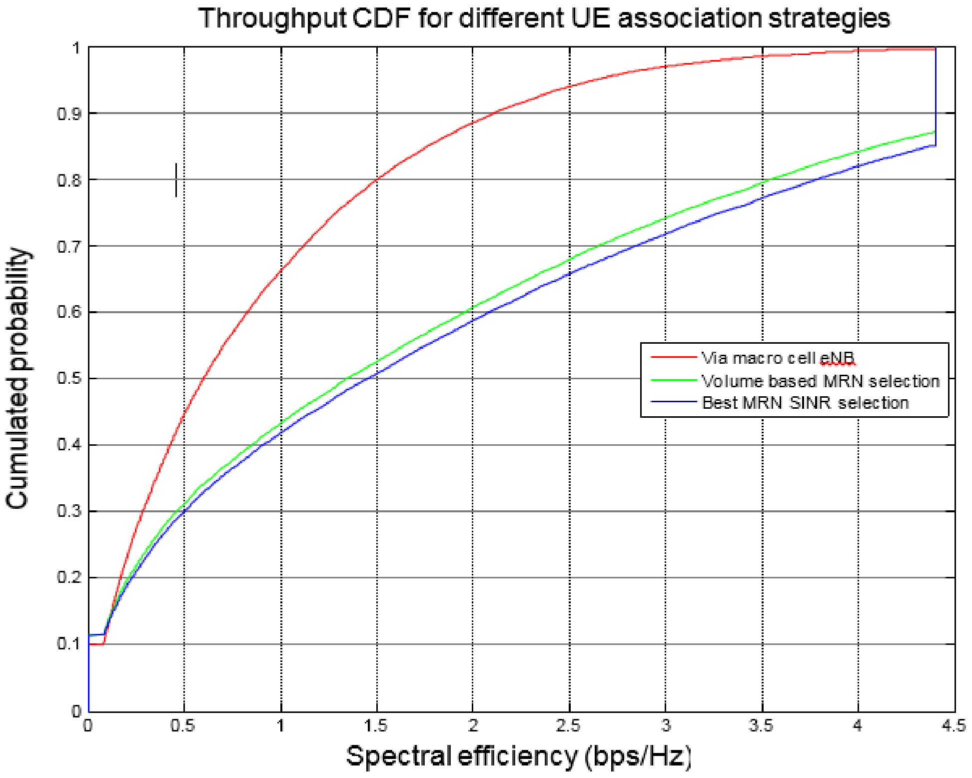

Figure 12. CDF of throughput for all strategies with interference when the eNB power is 30 dBm, and where the MRNs and the UEs are in the outer 20% and 10% of cell area, respectively

Figure 12 shows that the throughput with relay assistance is always higher than direct eNB-UE (0.6 bps/Hz at the fifty percentile). For the fifty-percentile using the volume based MRN selection, the throughput is around (1.4 bps/Hz) and using the best-SINR MRN selection the throughput is around 1.3 bps/Hz. The Sinr to throughput mapping is explained later.

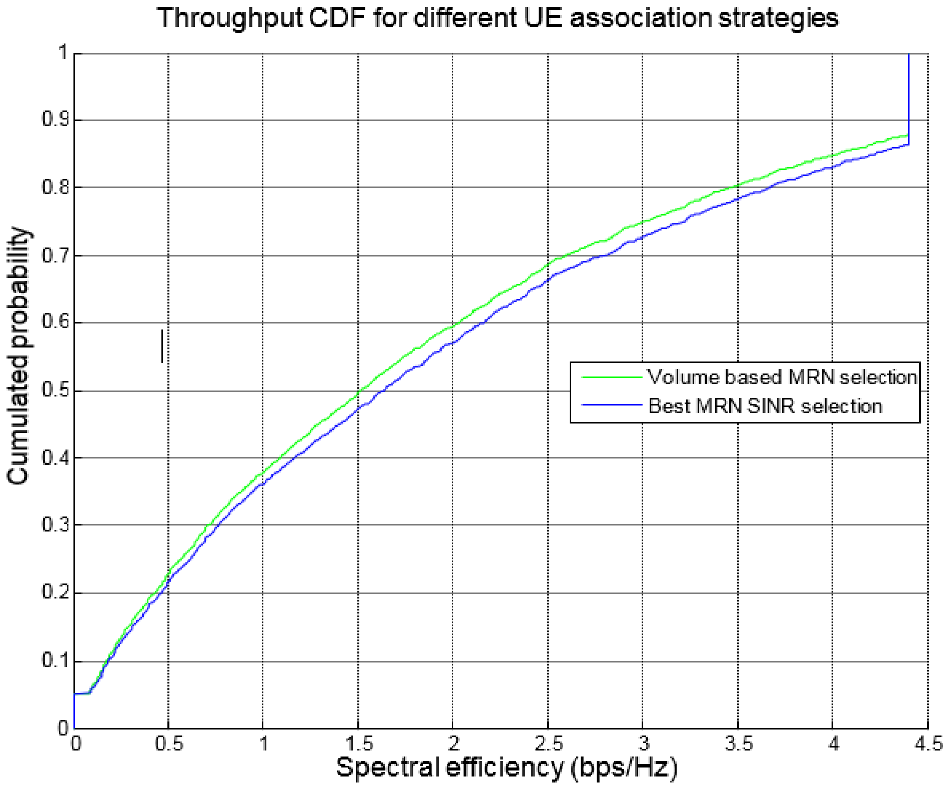

Figure 13. Spectral efficiency for both strategies with 35 MRNs in the cell and 50 UEs

In **Error! Reference source not found.**, we increased the number of MRNs in the eNB cell area for the same number of cell-edge UEs. Comparing to Figure 12 the throughput for both strategies has been improved since this increases the chances for a UE to find MRNs that meet time of connection constraint and offer them higher SINR value.

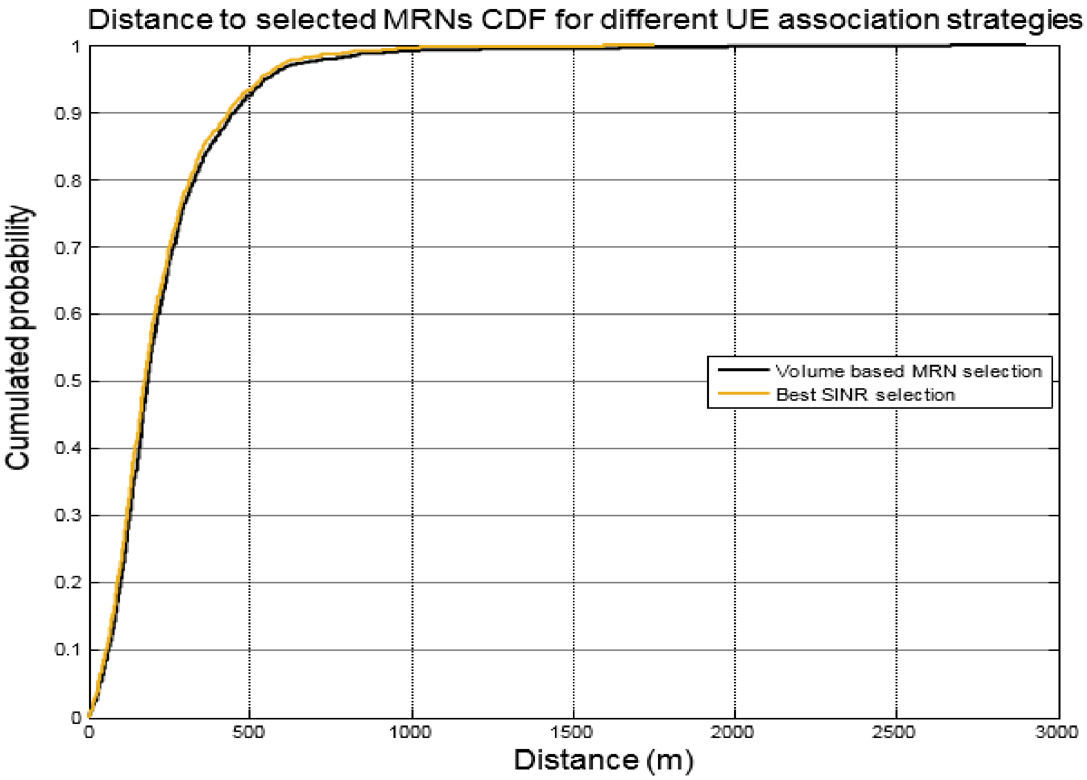

Figure 14. : CDF of distance for all strategies with interference when the eNB power is 30 dBm, and where the MRNs and the UEs are in the outer 20% and 10% of cell area, respectively

Figure 14 shows that the probability of average distance to selected MRNs less than 250 m is 0.7 for both strategies but for a distance less than 500 m, the probability with best SINR selection is 0.9 while for volume based MRN selection this probability is lower (0.84).

The results demonstrate the benefits of the volume-based strategy used. The same observations are noted in **Error! Reference source not found.**, and where we compared the CDF of time of connection and the average distance for random MRN/UE position drops.

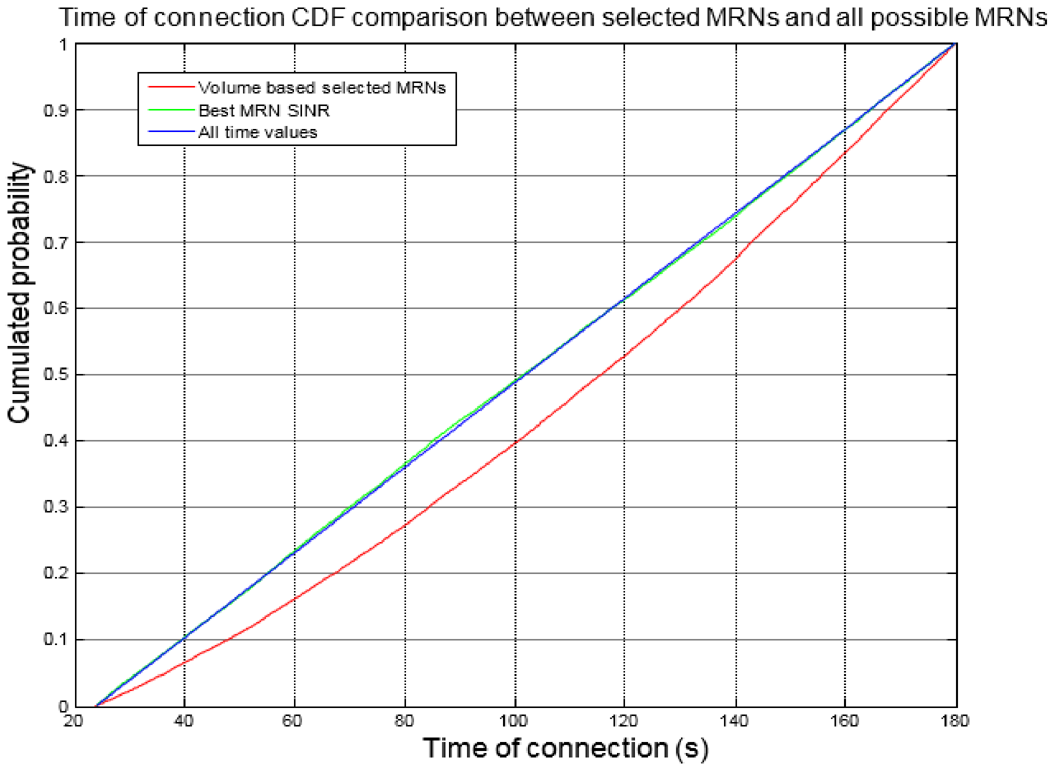

Figure 15. CDF of time of connection with interference when the eNB power is 30 dBm

Error! Reference source not found. shows the CDF of time of connection where MRNs and UEs are in the outer 20% and 10% of cell area, respectively. It also proves that volume based selected MRNs strategy is better than the remaining possible selection. (i.e to get a time of connection greater than 120 s its probability is 0.48 with volume based selected MRNs and 0.28 with best MRN SINR)

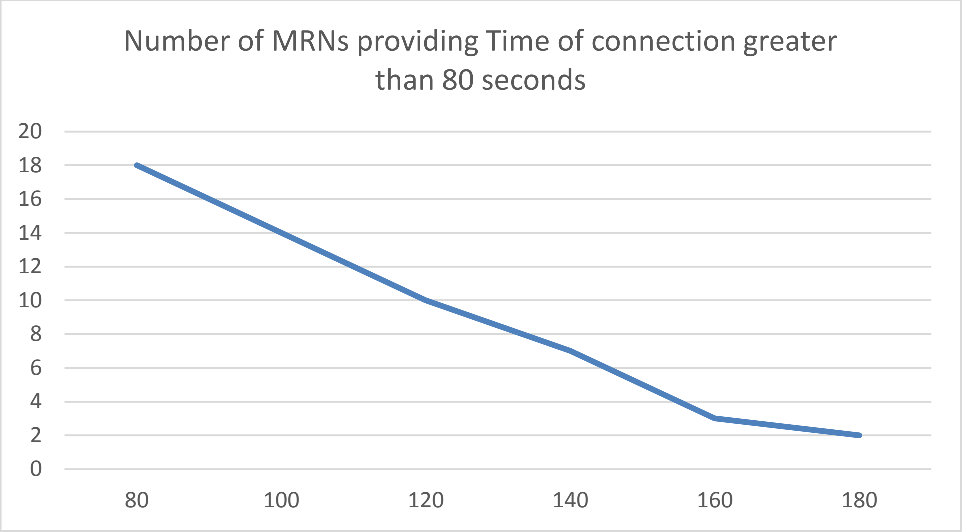

Figure 16. : Number of MRNs providing Time of connection greater than 80 seconds

Error! Reference source not found. shows MRNs that can provide a time of connection at least of 80 seconds for UEs. For example, eighteen MRNs out of twenty-eight are providing time of connection at least 80 seconds

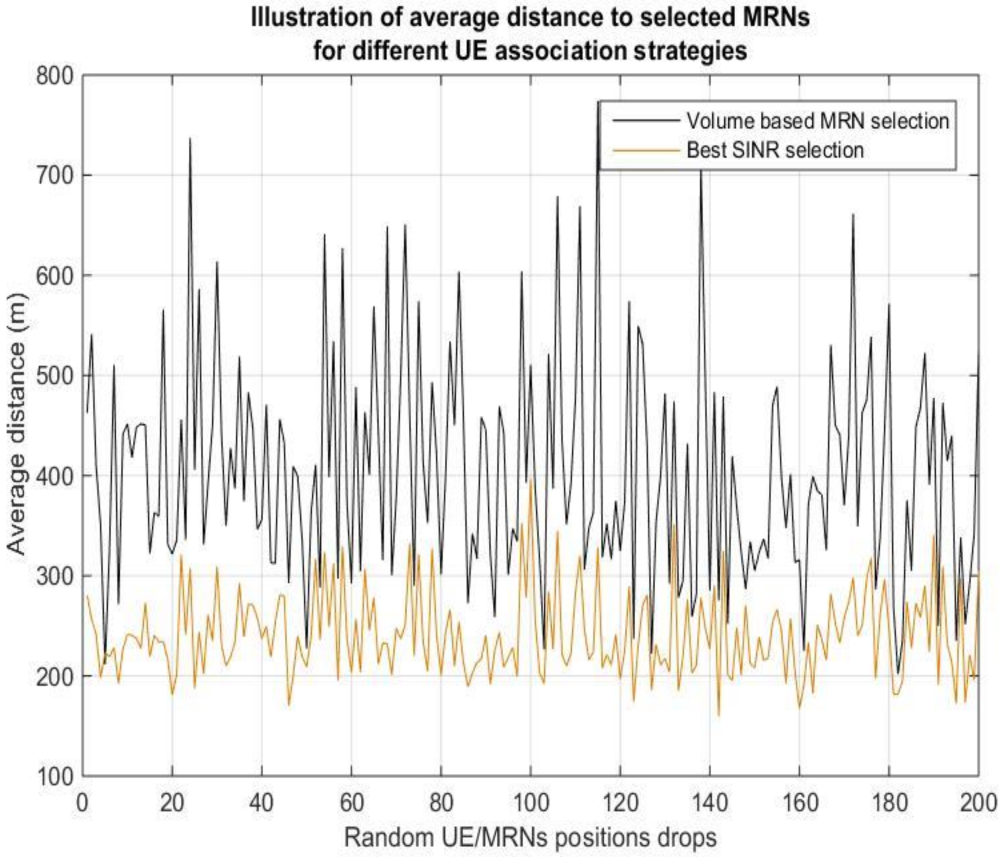

Figure 17. Average distance for all strategies with interference when the eNB power is 30 dBm

Error! Reference source not found. shows the average distance for both strategies where the MRNs and the UEs are in the outer 20% and 10% of cell area, respectively. The distances between UE and MRNs when using the volume based MRN selection is higher in average than distances when using best SINR selection and this result show that UEs with this strategy can enjoy higher time of connection even when the distance separating them from MRNs is getting bigger.

2. ***Case 2: No Intra-cell frequency reuse***

In most of the works in the literature on MRNs, indoor UEs are considered [6] [19]. That is, MRNs antennas are placed on top of vehicles, meaning that the distance between an MRN antenna and a UE is only few meters, and hence, a high gain may be expected. In our case, on the other hand, the MRN-UE distance is variable and can increase to hundreds of meters. Thus, the MRN selection scheme must consider the time of connection in addition to a sufficiently large SINR, although a careful MRN pre-selection based on positions and proximity to the cell-edge is needed.

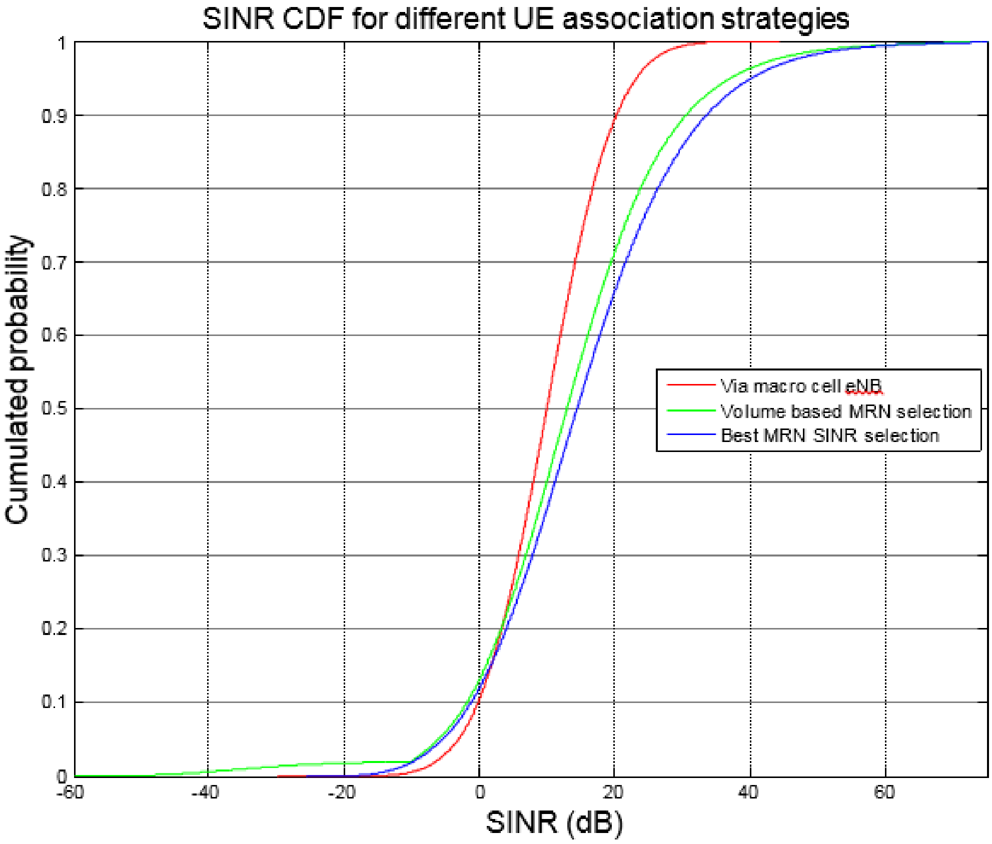

Figure 18. CDF of SINR for all strategies without interference when the eNB power is 40 dBm, and where the MRNs and the UEs are in the outer 20% and 10% of cell area, respectively

Similar observations as in the previous subsection can be made for this case, with the difference being that the curves cross at an SINR value of around 3 dBs, as seen in Figure 18, which can be explained by the high interference from the eNB in Case 1.

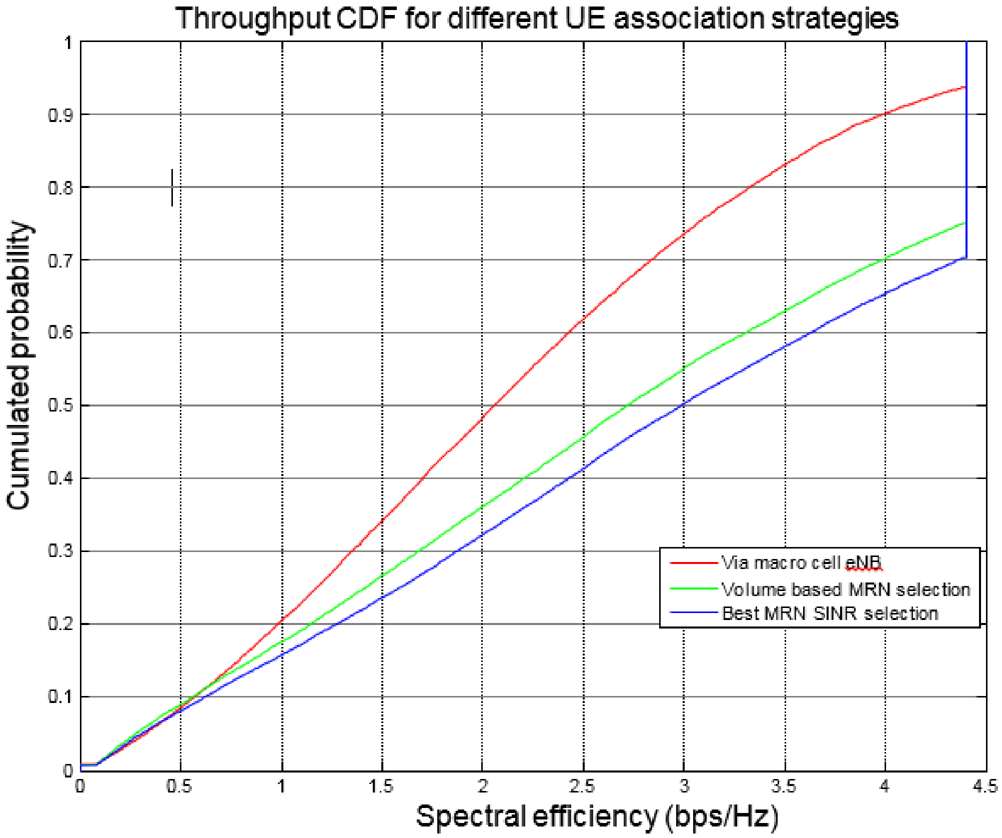

Figure 19. CDF of throughput for all strategies without interference when the eNB power is 40 dBm

Figure 19 represents the throughput in scenario without interference where the MRNs and the UEs are in the outer 20% and 10% of cell area, respectively. It shows that the fifty-percentile throughput is increased by 33% (with volume based MRN selection) and 23% (with Volume based MRN selection) using the two selection strategies when we compare the fifty-percentile throughput in case 1 (Intra-cell frequency reuse) to case 2 (No Intra-cell frequency reuse) . Figure 18,Figure 19.

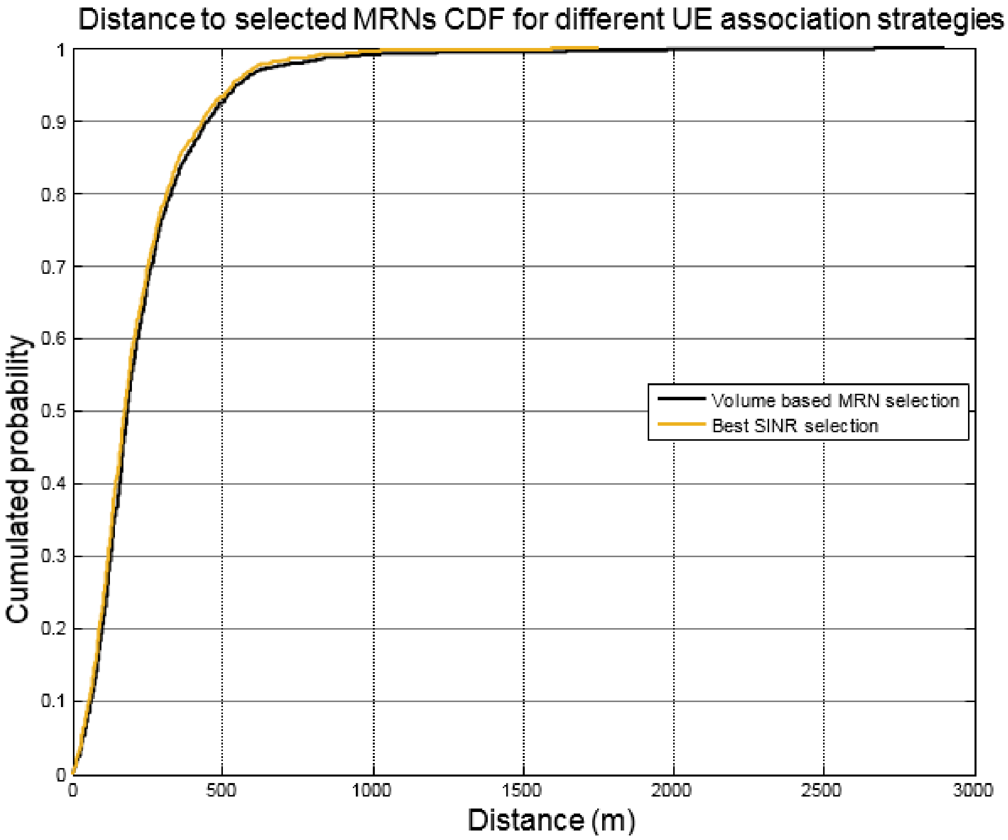

Figure 20. CDF of distance for all strategies without interference when the eNB power is 40 dBm, and where the MRNs and the UEs are in the outer 20% and 10% of cell area, respectively.

Also, in the case without interference as we see in Figure 20, the two strategies have the same CDF distance behavior where the MRNs and the UEs are in the outer 20% and 10% of cell area, respectively. This can be interpreted by the absence of interference

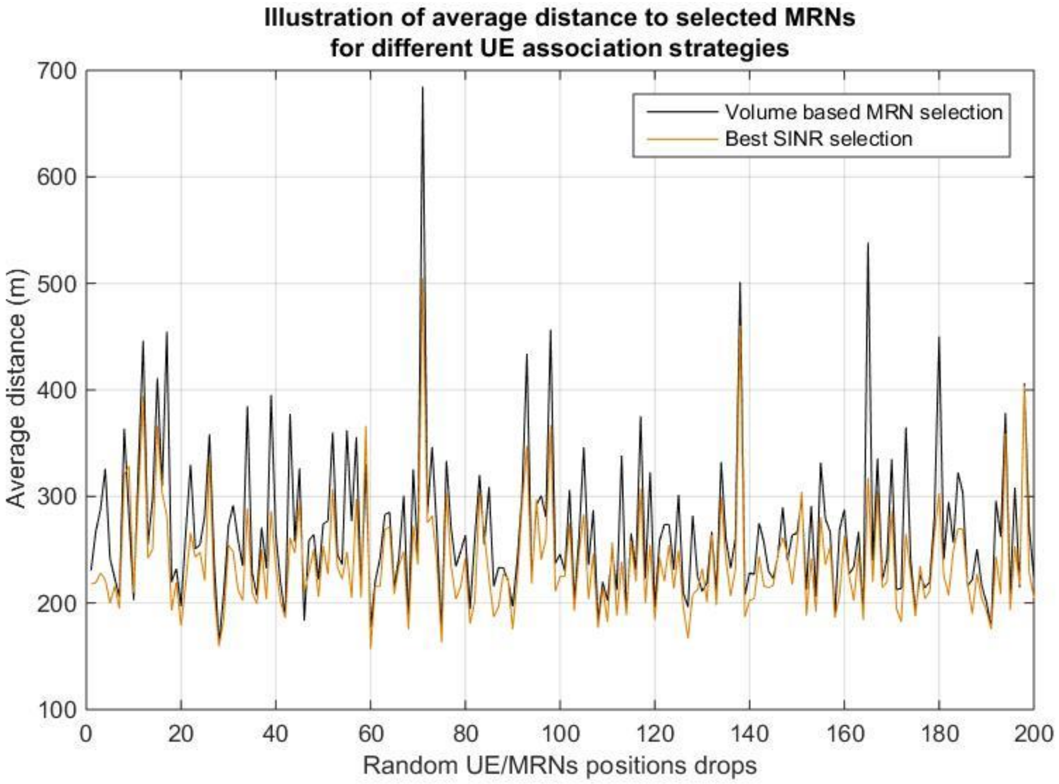

Figure 21. Average distance for all strategies without interference when the eNB power is 40 dBm

Comparing Figure 20 to Figure 14 we note that the average distance to selected MRNs where the MRNs and the UEs are in the outer 20% and 10% of cell area, respectively.

with volume based MRN selection still greater than Best SINR selection but with a very small amount. This difference is due to the absence of interference.

D. Impact of relay’s speed on throughput

In our work we assumed that all MRNs are running at a velocity of 30 km/h. At low velocity, UEs benefit from more static channel conditions and more expected time of connection. When the MRN speed increases SINR values change faster and expected times of connection decrease. In our system we plotted the spectral efficiency for two strategies (Best MRN SINR selection and volume based MRN selection) in Figure 22**Error! Reference source not found.** At the fifty percentile of throughputs we observe that when speed increases the spectral efficiency decreases.

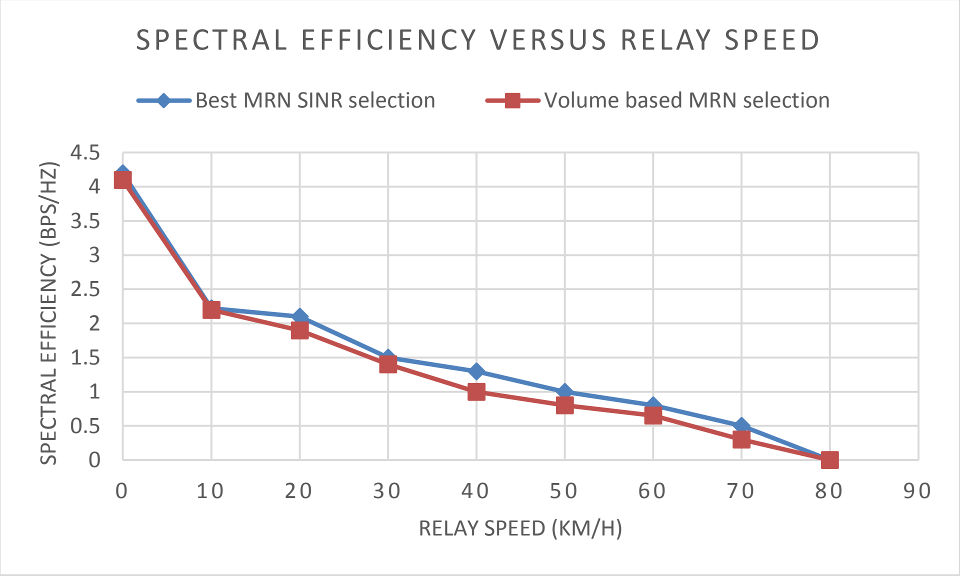

Figure 22. Spectral efficiency versus relay speed

In the work presented in [12] the scenario considers a single cell with multiple Mobile Femtocells (MFemtocell) and multiple users. The MFemtocell is formed by a relay node that fully decodes and re-transmits data. The performance of the MFemtocell was evaluated, where the MFemtocells and mobiles users are distributed independently, and the users inside the MFemtocell were assumed to be indoor users with a 5-dB penetration loss. We should note that the UEs they treated are indoor UEs and that

The Cumulative Distribution Functions (CDFs) of the user and MFemtocell average throughputs are presented in the figure below. The MFemtocell deployment can increase the average throughput of the users. The bandwidth used is 10 MHz and is used to un to make it comparable we divided their results by the bandwidth to have the same units as the second figure which is the throughput in our scenario. The table below shows the comparison of the improvement achieved in both scenarios.

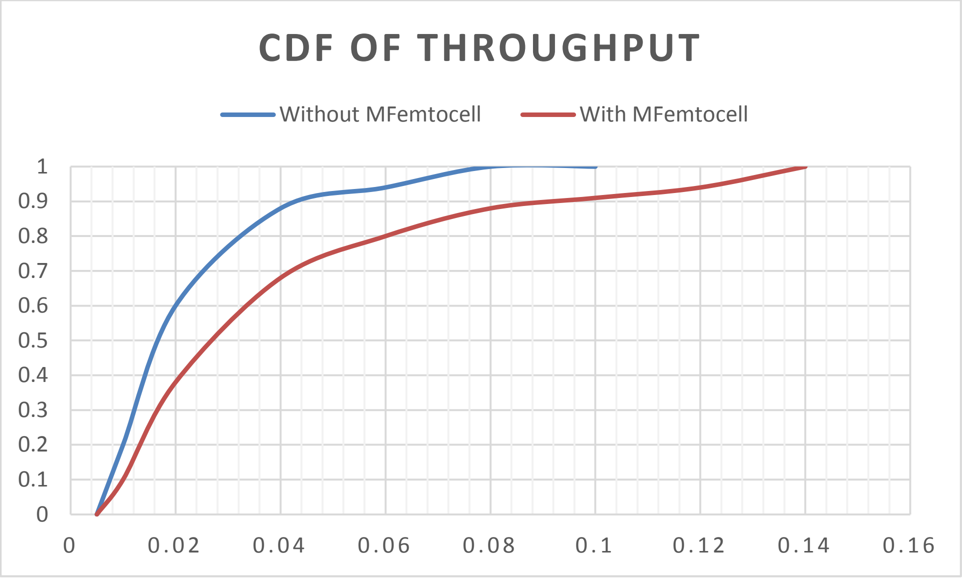

Figure 23. CDF of throughput generated in paper [12]

To compare the throughput, we divided the values they generated by the bandwidth to get the spectral efficiency that we generated and we compare the values at the fifty-percentile in the table below

UE throughput at fifty-percentile	**scenario (mobile relays)**	**scenario (mobile femtocell)**
Without moving network	0.6 bps/Hz	0.017 bps/Hz
With moving network	1.5 bps/Hz	0.029 bps/Hz
Throughput improvement	2.5	1.7 times
Users	outdoor	indoor

Table 2. mobile relay versus mobile femtocell

CHAPTER V

CONCLUSION

Relaying has received significant interest in the wireless communication community and standardization bodies. It is meant to improve the cell edge coverage and performance through extending the reach of the base station. Mobile relays can offer attractive advantages over fixed relays in terms of reduced cost and their suitability to varying network connection demands, when exploiting the availability of public transportation vehicles, such as busses that roam streets at relatively low speeds. Indoor UEs with respect to the MRN has been studied to a certain extent in the literature, whereas in our work we have explored the use of mobile relay nodes for outdoor UE connectivity enhancement. This makes achieving a gain not straightforward, and this requires the consideration of other parameters, like the duration of the connection time. We proposed a system simulation framework and identified cases of relay distribution where the use of mobile relays can be beneficial. Two UE-relay association strategies have been proposed an evaluated taking into account two interference scenarios. The conclusion is that a network operator can achieve a significant gain through exploiting mobile relaying by using relays that are relatively close to the UEs. The 50%-ile throughput doubles (between 1.3 and 1.4 bps/Hz using MRNs, when compared to 0.6 bps/Hz using direct connection) in the case of intracell interference, while a 50%-ile throughput is increased by 23% to 33% (using the two strategies) in the absence of intracell interference.

In future works, advanced scheduling and resource allocation schemes can be evaluated, as well as estimating the amount of signaling overhead reduction by studying the variation and change behavior of SINR values.

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