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Road Based Mobility with Network Information Services

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Abstract

Increasing traffic demand and mobility pose many challenges for wireless networks. Lack of sufficient wireless resources and attempts to fix the problem by equipping networks with more small cell base stations challenge mobility managers. Network information services have been widely cited to help mobile users and networks cope with increasingly dense heterogeneous network environment. In this paper, an information service enhanced with information about base station coverage areas and expected driving routes of end systems are used as basis to improve mobility. Especially, emergency and other high-priority vehicles with pre-known driving routes could benefit from the proactive selection of base stations and their configuration to guarantee quality of service throughout the traversed path. The results indicate that the demanded quality is likely not met when networks suffer from congestion. Moreover, cell selection based on the known route can decrease the number of handovers even almost by half compared to the traditional algorithm using signal strength measurements as basis for the handover target selection.

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Keywords: Coverage area; heterogeneous networks; information services; mobility management

1. Introduction

Substantially growing data traffic over cellular networks can cause big variations in the Quality of Service (QoS) when handing over base stations (BSs) in a heterogeneous network environment. Traffic loads in networks and individual BSs vary, which can cause increased transmission delays and packet losses. Moreover, the average cell size is anticipated to decrease in the future in order to better cope with the increasing capacity demand. This poses challenges especially for high-speed vehicular mobility as the number of handovers can potentially increase significantly when the traditional cell selection scheme, based on the strongest signal criterion, is used.

More and more, emergency vehicles are capitalizing on wireless networks to get remote assistance or to inform other parties of emergency situations in real-time. For example, wireless telemedicine will play an important role in the evolution of the Internet[1]. The utilization of wireless networks in emergency situations is not related to only voice

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and text messages, but, for example, real-time video and 3D image transmission take place more often. In emergency cases, the delivered content is also often intolerant for errors, such as in the case of the delivery of biomedical data. Thus, the BSs and networks used by emergency vehicles should provide a guaranteed QoS for their applications, even in high-speed mobility.

In this paper, we study how the knowledge of the driving routes of high priority vehicles can be utilized in the handover target selection and preparing the networks to guarantee a satisfying QoS across the route. The current mobile devices are capable of knowing their geographic location within a few meters. Moreover, the driving routes of, e.g., emergency vehicles are often known in advance. This study utilizes a network information service, which allows querying for networks and BSs nearby of mobile stations. Network information services are specified in IEEE 802.21 Media Independent Handover (MIH) Services[2] and 3rd Generation Partnership Project (3GPP) Access Network Discovery and Selection Function (ANDSF)[3] standards. Those standards facilitate cellular network users to seamlessly switch to heterogeneous networks expected to satisfy the required service level. The information services of both standards are observed similar, as studied in[4]. One clear difference is that ANDSF supports Mobile Network Operators (MNOs) to define policies for end system handled network selections. Policies are out of scope of IEEE 802.21. However, neither of the standards allows determining the operational areas of BSs with sufficient precision. Thus, the BS coverage area enhanced information service presented in[5] and first studied in mobility scenarios in[6] is exploited in this paper. The goal of the paper is to evaluate the importance of QoS assurance for high-priority data traffic when BSs with different probabilities suffer from congestion, and the BS cell selection to decrease the number of handovers when the driving route is known.

The rest of this paper is organized as follows. In Section 2, the related work is presented. Section 3 introduces the route based mobility solution. Section 4 presents the evaluation results of the solution and Section 5 concludes this paper by outlining also future work.

2. Related Work

Overall, network information service assisted mobility is not thoroughly studied in the open literature. The benefit of IEEE 802.21 information service, known as Media Independent Information Service (MIIS), for improving handover performance through network pre-authentications is studied by Christakos et al. in[7].

Location based network selection has been studied in many papers. Pawar et al. present a QoS-aware and location based network selection mechanism in[8]. However, their solution does not indicate reliably the coverage areas of networks, much less about individual BS cells. Proactive handover management based on previously recorded data about networks in different locations is studied by Kovacs et al.[9]. The solution predicts handover locations based on earlier experience and utilizes multihoming to minimize the disruption of handovers to QoS. However, the solution proposes that each mobile router maintains its own database, which is not efficient. Moreover, the collected data is not efficiently utilized in the selection of handover target network. Shi et al. have studied navigation based on network quality in[10]. The selection of driving route based on networks that can satisfy the required service level can potentially result in longer traveling distances. This trade-off can often be unacceptable for high-priority vehicles, such as emergency vehicles. Dutta et al. have studied location assisted handovers in[11]. They exploit both mobile device's location information and signal quality in the handover decision making, but use only a relative location of the mobile device with respect to the close-by networks, neglecting the analysis of BS coverage areas.

Many of the location based mobility solutions are related to network selection, not on cell based handover management. Cell selection plays a more essential role in the future wireless networking due to the change of mobile network infrastructure to increasingly favor small cells such as femtocells, picocells and microcells. Cell selection algorithms in a heterogeneous network environment have been studied in a number of papers, however, most of those are based only on the signal strength criterion. The studies carried out by Bai et al.[12], Chowdhury et al.[13] and Wang et al.[14] observe the challenges posed by heterogeneous networks with different size cells on the optimized mobility.

3. Route Based Mobility Optimization

Fig. 1 illustrates a heterogeneous network environment typical of the future wireless communications. Within large macrocells, several femtocells, picocells and microcells are deployed to sufficiently keep up with regional traffic

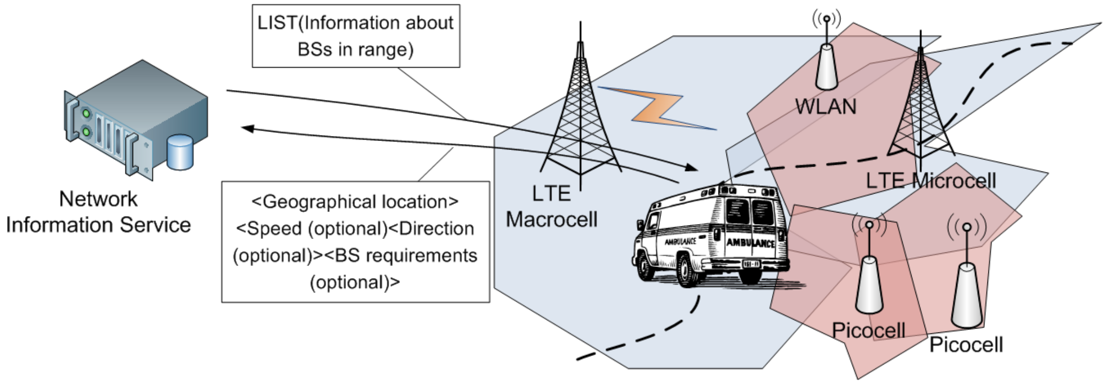

Fig. 1. Information service assisted mobility.

demands and to fill the possible coverage holes of macrocells. Different MNOs also have a varying coverage in different regions. Thus, it is recommended that the emergency vehicles utilize the network infrastructures of multiple MNOs. In this case, the number of nearby BSs discovered as potential handover targets increases substantially. In addition to cellular BSs, the number of open WLAN hotspots, either public or MNO provided, has proliferated. The number of public hotspots is anticipated to grow by 350% from 2011 to 2015[15], to reach the level of 5.8 million worldwide.

A large number of access points in the range of a mobile station not only provides more possibilities to find the Internet connection but also makes the selection of the most suitable wireless access much more challenging. Dynamic signal strength based BS selection does not perform optimally when the number of overlapping cells is high, especially if they operate in different frequency bands or are based on different access technologies. Before the connection is established, its suitability for the ongoing services must be found out. Discovering the suitability without tests over an active connection is difficult. However, network information services allow end systems to discover networks at or near their current location and query for information about them. The current standardized information services specified in the IEEE 802.21 and 3GPP ANDSF standards consider information such as frequency band, BS location, network address, and overall BS capabilities, like the supported QoS service classes. However, the operational range of BSs can be determined only based on the access technology and the BS location. The BS coverage area information presented in the papers[5,6] benefit the mobile devices by finding the cells observed to cover their current location or the expected location in the near future through a single query carrying their geographical coordinates. The coverage areas of BS cells are stored in a spatial database as polygon geometries. The coverage polygons stored in the database need to comprise a relatively strong signal strength area, e.g. -80 dBm, to cope with different mobile devices with different radio sensitivities. However, it is also feasible to have several coverage areas, each with a different signal strength level. It is important that the database reflects the prevailing situation regarding the coverage areas, which necessitates frequent updates of the database, possibly carried out with the help of end systems.

In emergency situations, when the driving route of vehicles, such as an ambulance, is known, the BSs can be selected prior to the driving with the assistance of the coverage area enhanced information service. When the BSs opted to be used are selected, a request to MNOs to configure the selected BSs to guarantee a high and consistent QoS can be sent. The QoS can be assured, for example, by offloading some of the current users to other BSs and networks, limiting the user number, and adjusting traffic priorities. However, due to the nature of wireless communications, unexpected handovers are possible. Moreover, driving route changes can happen because of traffic jams. Thus, alternatively, the traditional dynamic cell selection can be improved by selecting the cell that can likely provide the longest connection. This scenario is illustrated in Fig. 1 where the mobile device sends its current location to the information service, which returns the BSs that cover the inquirer's current location. In order to reduce the amount of information returned by the information service, the inquirer could indicate its current driving speed, heading direction, and possible BS requirements, such as the support for QoS classes. When BSs are selected dynamically on the way, the selection of handover targets should be made seconds before the actual handovers in order to leave networks sufficiently time to make the required configurations and changes for the QoS guarantees[16]. Usually, the QoS service classes assigned to users cover the whole network of MNOs. However, when the service requirements vary, BSs are employed by different numbers of users with varying priorities and networks of multiple MNOs are used, fixed service class configurations and assignments do not result in an optimal usage of network resources.

3.1. Cell Selection

The paper[6] studies the impact of overlapping and differently sized cells on the number of handovers in high-speed vehicular mobility. The paper proposes the cell selection to be based on a clustering method to reduce the number of BSs taken for a closer assessment. This is especially beneficial in dense BS environments. The BSs found to cover end system's location are clustered with the *k*-means method to four groups based on the distances to the BSs and the cell coverage areas. Once the BSs are clustered, the algorithm selects the cluster, whose centroid describes the optimal target BS best. For the high-speed mobility, this is the cluster where the distances to the BSs are relatively short and the cell areas are large. Large cells can potentially decrease the number of handovers. Like measured in[17] in a live 3G UMTS network and in[18] in a 4G LTE network, handovers, weak signal level before it, or both introduce increased delays and affect the service quality. Nevertheless, the longest duration connection can also be provided by a large BS cell located far, which is often grouped to a different cluster than that selected. However, the relatively short distances to the potential candidate BSs is favored by the algorithm because the traveling route of mobile users is usually unknown to mobility management entities. In addition, when the signal strength is high in the beginning of a new connection, the signaling related to handovers and the lossless continuation of ongoing services likely succeeds with more certainty. This is the reason why the BSs in the cluster whose centroid indicates far distances are neglected also in this study, although in some cases they could provide the longest term connection points.

In[6], there was no further assessment carried out for the BSs in the cluster selected as optimal. In this paper, the cell selection is improved by selecting the BS which can provide the longest connection for the mobile user. This presumes that the traveling route is known, such as in the case when an ambulance heads to its respective hospital.

4. Evaluation

The proposed solutions to optimize the mobility of emergency vehicles and to improve the cell selection based on pre-known driving routes are evaluated with simulations. The simulations are carried out in a square area with side lengths of 20 kilometers. The measurement area is equipped with 2,000, 3,000 and 4,000 cells randomly located within the measurement area. As the aim of the evaluation shown in this paper is not to study any specific environment (terrain, buildings, vegetation, etc.), the random BS locations are sufficient for this evaluation. The BS coverage areas are depicted as polygons and stored in a spatial database, PostgreSQL of version 9.1.5 with PostGIS extender of version 2.0.1. The simulator is implemented in Perl and use a DBI module as the database interface.

The cells created are of similar shape heptagons. However the beam direction of each cell is randomly selected. Moreover, the sizes of the cells vary. The cells are meant to roughly represent realistic femto, pico, micro and macrocells. The cell range (R) is a uniformly distributed random value between R^c_{min} and R^c_{max} shown in Table 1 for each cell type used. The evaluation is performed with two different cell type distribution scenarios, shown in Table 2. Scenario 1 (S1) includes more macrocells while Scenario 2 (S2) deploys more small cells with the proportion of only 20% macrocells. Thus, S2 likely reflects the future BS infrastructure better. In case the mobile station has access to the BS infrastructures of multiple MNOs, the mobile station can capitalize on many overlapping macrocells, which is better reflected by S1. In general, the coverage areas of IEEE 802.11 hotspots are comparable with femtocells and picocells.

Table 1. Cell ranges.

	Femto	Pico	Micro	Macro
R^c_{min} (m)	10	20	100	600
R^c_{max} (m)	20	100	600	2000

The vehicular mobility in the simulations was emulated by going randomly across the measurement area. The measurements were repeated 100 times and for each run a new random measurement area was created. First, we

Table 2. Scenarios for cell type distributions.

Scenario	Femto	Pico	Micro	Macro
S1	0.05	0.15	0.2	0.6
S2	0.1	0.4	0.3	0.2

evaluate the mobility performance in cases where BSs with different probabilities cannot meet the QoS requirements. The probabilities used for bad BS cells in the simulations are 30%, 50% and 80%. The cells are randomly marked as bad according to the given probabilities and always the nearest cell is selected in handovers. The simulations do not consider any specific QoS parameters that translate into the unacceptable service level, but use congestion and the best effort scheduling scheme as causes for the unsatisfactory QoS. Generally, congestion is a major cause for the unsatisfying QoS in BSs, which causes packet losses, and increased delays and jitters. Traffic loads in BSs can rapidly change, which makes in advanced performed estimations of the available bandwidth in the handover target networks difficult, advocating QoS monitoring and guarantees for the most important users and applications. However, low signal quality leads to a varying QoS as well, which can be prevented by proactive handovers with the assistance of the coverage area enhanced information service. How delays and packet losses affect the service quality varies between different applications. For example, for voice, a 5% packet loss often results in an intolerable quality [19]. Several application-specific models exist to estimate the quality perceived by the users (Quality of Experience, QoE) and some of the models are able to perform the estimations also based on network QoS measurements (e.g. packet loss and delay) [20,19].

Another evaluation of this paper assesses the BS selection algorithm, which looks for the handover targets that can serve the mobile station the longest without a new handover. As the driving direction is known in advance, the coverage areas of the discovered BSs in mobile station's upcoming locations are tested with the granularity of 50 meters. The BS with the longest distance is selected as the handover target. The evaluated cell selection scheme applies to a dynamic handover target assessment and selection. The cell selection scheme does not assess all possible cell combinations beforehand, which theoretically results in a fully optimized cell selection, provided that there are no unexpected driving route changes.

The simulation environment does not implement any link budget calculation but the cell coverage areas and handover target candidates are based purely on those stored in the information service database. Moreover, the goal of the mobility evaluation is related to the handover target selection and the impact of handover procedures on the QoS is neglected. Commonly, in a handover performed on Layer-3, there is a risk of losing some packets during the handover procedure, while Layer-2 mobility in novel access technologies is mostly lossless. However, also each Layer-2 handover introduces signaling within access networks and incurs additional transmission delays that can affect the service quality [17]. Even in the state-of-the-art access technologies, handovers cause interruptions for data flows in the magnitude of several tens of milliseconds, measured to be about 80 milliseconds in LTE [18].

4.1. Mobility with Varying QoS

Fig. 2 shows average results for the success of mobility when BSs with the different probabilities are unable to provide the sufficient QoS. Overall, between different numbers of BS cells in the measurement area, there is no significant difference observed in the proportional numbers of handovers to the cells perceived as incapable of providing the adequate QoS. The results also show that the used probabilities for cells considered as unsuitable well indicate the average proportions of handovers to the bad cells. However, already with the probability of 50% of bad cells, a few measurement runs ended up selecting only cells with insufficient QoS, more pronouncedly in S2.

The bad cells are uniformly distributed between each cell type. In S1, a larger number of macrocells makes the probability to hit the coverage area of bad cells higher. In S2, the larger proportional ratio of small cells results in a smaller total area covered by unsuitable cells. However, in S2, the expected number of handovers is higher due to smaller cells. Which of these criteria affects the mobility performance more is observed to depend on the number of BS cells in the measurement area. With 3,000 cells in the measurement area, S2 results in a better mobility performance, while with 2,000 and 4,000 cells, S1 generally leads to a smaller proportional number of failed handover

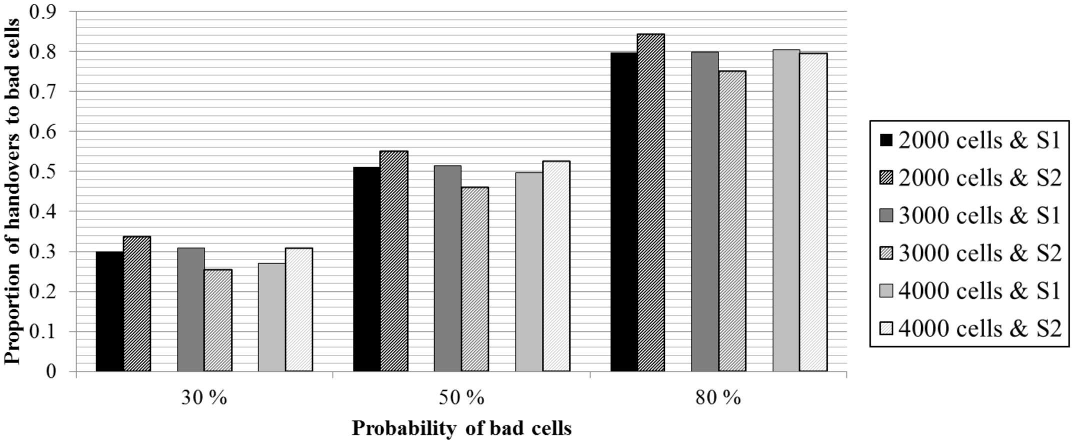

Fig. 2. Proportion of handovers to cells with insufficient QoS level.

target selections. With the probability of 30% bad cells and 3,000 cells, the handover success rate is almost 20% better in S2 than in S1. With 2,000 and 4,000 cells, S1 results in over 10% better cell selection.

When the probability of bad cells in the measurement area reaches 80%, high quality mobility becomes practically impossible without any privileging resource sharing in the BSs/networks visited. On average, almost 80% of the handovers are made to unsatisfied BSs, reaching even 100% in more than one tenth of the measurement runs. Common for all measurement scenarios is that the standard deviation of the number of handovers to unsuitable cells between the measurement runs is in the magnitude of 20%, except with 4,000 cells and S1 slightly exceeding 10%.

4.2. *Cell Selection Based on Driving Route*

Fig. 3 shows the results obtained with different cell selection algorithms in terms of the number of handovers. The non-optimized algorithm chooses the closest BS, which attempts to emulate the strongest signal strength algorithm traditionally used in today's mobile networks. The cell selection algorithm presented in[6], based on the cell clustering, is used in the results shown as cluster optimized. The clustering based algorithm is improved to consider the driving route in the selection of the optimal handover target.

The average number of handovers with the non-optimized cell selection is observed to be nearly 50% more than that made with the cluster optimized cell selection scheme. The reason for this is that only large cells, when available, are considered as handover targets in the cluster optimized solution. The number of handovers with the cluster optimized scheme stays on a similar level regardless of the number of BS cells in the measurement area.

The route optimized algorithm improves the performance even more. In S1 and with 3,000 and 4,000 cells, the number of handovers can be decreased even by over 20% compared to the cluster optimized scheme, which randomly selects the handover target from the optimal cluster. In S2, where the ratio of small cells is larger, we observe that the cluster optimized scheme results in less handovers than the cluster and route optimized scheme with 2,000 cells. The average number of overlapping cells in S2 is about three times lower than that in S1. For example, with 2,000 cells, on average, only four overlapping cells are discovered in S2. This does not translate into sufficient cell diversity in order to the route optimized cell selection scheme to get benefit over the cluster optimized scheme. The route optimized scheme studied selects the cell that can serve the longest but it does not consider the required cell changes beyond the coverage area of the selected cell. Thus, not all possible cell combinations are calculated in order to fully optimize the cell selection. With 3,000 and 4,000 cells in the measurement area, the gain of the combined cluster and route optimized scheme does not bring significant gain either. The average number of overlapping cells with 4,000 cells is eight and the gain of the route optimized scheme is only one handover less than that got with the cluster optimized scheme.

Fig. 4 shows the average distances the mobile device is connected to each cell in relation to the non-optimized scheme. In S1 and 2,000 cells, the route optimization in the cell selection provides over 70% longer average distance

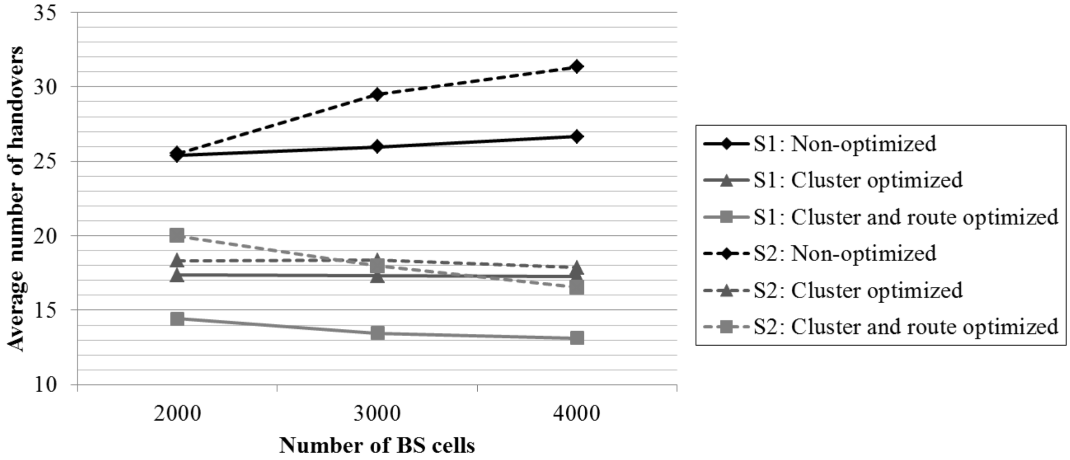

Fig. 3. Number of handovers.

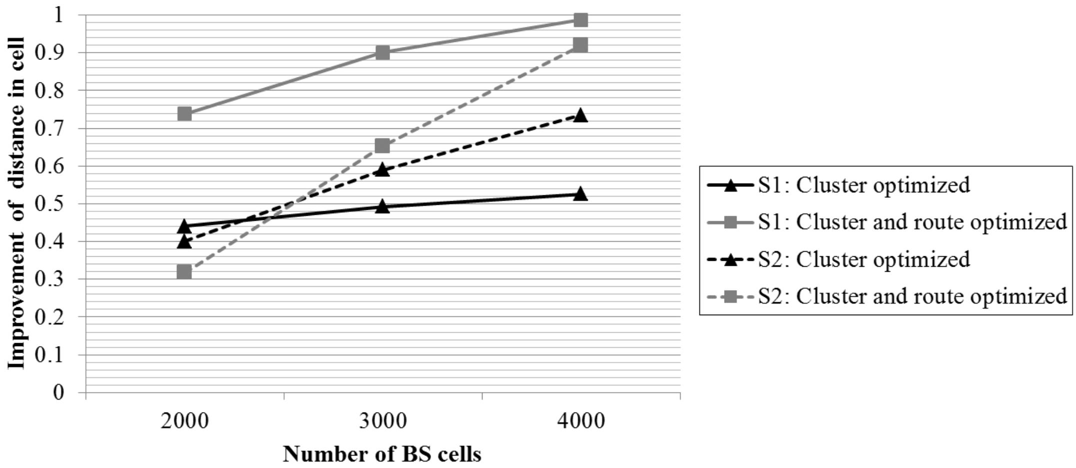

Fig. 4. Improvement of average distances in cells compared to the non-optimized cell selection.

in each cell, being 776 meters with the non-optimized scheme. With 4,000 cells, the average distance per cell is almost twice the distance of the non-optimized scheme.

As already seen in Fig. 3 with 2,000 cells and S2, the route optimized scheme does not bring benefit with respect to the number of handovers when compared to the plain cluster optimized scheme. The random cell selection from the cells discovered to be the most potential ones, based on their coverage areas and the distances between the BSs and the mobile device, works, on average, better when the number of overlapping cells is small. With 4,000 cells, the route optimization provides even 26% longer average distance in cells when compared to the result of the cluster optimized scheme. However, as observed from Fig. 3, on average, only one handover less was performed with the route optimized scheme and with the same parameter setup.

5. Conclusions

To equip wireless networks with sufficient resources for the fast growing data traffic lags in many places. This congests certain regions and BS cells. However, many applications and users demand for a consistent and guaranteed QoS while switching BSs. Increasing deployments of small cell BSs attempt to mitigate the capacity shortage, however, making the network environment more heterogeneous and increasing the number of overlapping cells. This paper presented a solution, which utilizes the BS cell coverage area enhanced information service to improve the mobility of high priority users with known driving routes, such as emergency vehicles. Based on the information about cell coverage areas, the most potential BS cells can be selected in advance or in a proactive manner. When the BSs to be used are known, QoS guarantees can be configured and assured on a cell and application basis before connecting to them. This paper evaluated the route based mobility through simulations. The results showed that the requested quality can significantly degrade when handing over BSs with varying congestion levels and without any privileging QoS support over shared data channels. In addition, the known driving direction can cut the number of handovers almost by half when the cells are selected based on their ability to provide the longest term connections, instead of the strongest signal strength. High in the future work agenda is to improve the presented solution to also consider different QoS parameters for the BS assessment and to improve the road based cell selection algorithm further.

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