A Network Information Service for Quality-Driven Mobility

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***Abstract*—Fast growing data traffic over mobile networks pose many challenges for both end systems and networks to satisfy the required service levels of different applications. For end-users, the quality of experience (QoE), and consequently the underlying quality of service (QoS) are the most meaningful criteria for triggering handovers and selecting target base stations. However, difficulties in reliably measuring quality real-time have resulted in many QoS/QoE based mobility solutions being impractical. We propose a network information service that allows mobile devices to find suitable nearby base stations by indicating their capability to satisfy the required service level. Information services allow end systems to discover heterogeneous networks at or near their location. However, the current solutions do not enable assessing base station availability and their quality of service in different locations reliably enough. In our solution, end system performed QoS measurement (and possibly QoE estimation) results are stored in a spatial database within the information service as polygon geometries. Through a single query to the information service end systems can find a sufficient amount of information about base stations in range to make handover target decisions on quality of service basis. We observe that the solution can achieve quality improvements of up to 50% in dense heterogeneous networks.**

I. Introduction

Lack of sufficient capacity for the substantially growing mobile data traffic pose many challenges to mobile devices to provide users with satisfying quality. It is widely anticipated that the fast growth of data traffic will continue [1], in particular driven by media applications. Mobile network operators (MNOs) attempt to respond to the capacity demand by deploying new base stations (BSs), but insufficient spectrum availability already restricts network deployments. Small size BS cells and Wireless Local Area Network (WLAN) access points on unlicensed bands are increasingly been utilized to combat the capacity shortage. This makes the wireless network infrastructure more heterogeneous, posing increased challenges for mobility management.

Mobile devices still need to scan different bands for network announcements and beacons, which is not efficient in heterogeneous network (HetNet) infrastructures because scanning consumes resources. Relying only on scanning results can potentially result in non-optimal mobility. In order to better exploit the available wireless resources, IEEE and 3GPP have already specified standards to facilitate handovers in HetNets. IEEE 802.21 Media Independent Handover (MIH) Services and 3GPP Access Network Discovery and Selection Function (ANDSF) provide mobile devices mechanisms to query for information to assist in selecting heterogeneous BS cells that can provide the required service level. Both standards specify an information service as one of the main components, namely to provide static information about networks, access points and their capabilities. However, the current information services do not allow determining the coverage area of the target networks with sufficient accuracy, much less about the obtainable QoS.

In this paper, we propose to enhance the current information services with QoS information, which is based on end system performed measurements on field. The measured QoS parameters (delay, jitter, packet loss, etc.) are converted to a single QoS indicator with a quality model, which is stored in an information service database along with a location. The BS coverage areas are represented as polygons with different QoS values. Through a single query, a mobile device can find possible handover target networks and BSs and their respective expected quality level in its current location. The goal of this paper is to introduce our solution for QoS-based mobility management and to determine whether such solution can improve mobility in HetNets.

The rest of this paper is organized as follows. Section II relates this study to other QoS-based mobility studies. In Section III we present the information service solution proposed. The evaluation of the solution is presented in Section IV and Section V concludes this paper by outlining also future work items.

II. Related Work

QoS based mobility has been studied in a large number of papers. Many of them are based on an estimation of the available bandwidth, such as the papers [2], [3], and QoS estimation on signal quality basis, like in the papers [4], [5]. However, the available bandwidth is complex to be reliably estimated and active maximum throughput measurements consume resources excessively. Moreover, available bandwidth does not indicate QoS well as it neglects the delay and packet loss parameters. Received Signal Strength (RSS) and Signal to Interference plus Noise Ratio (SINR) do not give a reliable indication of QoS, either. The interference level can help assessing QoS, but, due to congestion, QoS can be very bad even in very good signal conditions. Typically, only very low signal qualities can be reliably utilized in QoS assessment, to betoken low QoS. Moreover, the signal quality thresholds, which result in a low QoS differs between different access technologies and mobile devices, which makes it a difficult QoS parameter.

QoE-driven mobility in HetNets is studied, for example, in [6], where real-time VoIP listening quality estimates are used to drive vertical handovers. In [7], the authors present a similar scheme for video applications.

Information services to improve mobility have not been thoroughly studied in the literature. The paper [8] evaluates the potential of BS coverage area information on cell selection. In the paper the coverage areas stored in an information service database are based on signal strengths. The results show that the number of handovers can be cut by up to 50% when favoring large macrocells instead of the nearest BS in the future HetNets. However, cell selection based only on signal strength does not correlate well with QoS and ultimately the user-experienced QoE, as mentioned earlier and therefore it is not suitable for quality-driven mobility as such. Christakos et al. have studied the possibilities of IEEE 802.21 Media Independent Information Service (MIIS) to improve handover performance through a pre-authentication with the target access point in [9]. The study utilizes the standard based information service, which does not enable assessing the attainable QoS levels in different locations. Bari et al. have studied the handover target network selection based on their ability to satisfy the required service level in [10]. The criteria used in the algorithm proposed considers, among others, the networks' availability in the user's geographic location and QoS related parameters such as delay, allowed bandwidth and packet loss. The architecture for the network selection comprises nodes that provide the algorithm information about network characteristics and services. Overall, those nodes correspond to today's network information services. The paper does not say how the dynamic information about networks is collected and measured.

Pawar et al. present a QoS-aware and location based network selection mechanism in [11]. They also utilize a service to indicate mobile devices about the QoS of nearby networks. However, their service does not indicate reliably the coverage areas of networks and the QoS is assumed to be the same throughout the networks. Resta and Santi introduce the Wireless QoS-aware Mobility (QiQoSM) model in [12]. The model considers user mobility, traffic model and wireless technology in defining the QoS to control the mobility behavior of users in wireless networks. The model allows networks to satisfy users' QoS requirements but do not allow mobile devices to assess the QoS in the target networks before connecting to them. In [13], Tamea et al. present a multi-criteria decision algorithm for mobility in heterogeneous networks. The ranking and selection of handover target networks is based on QoS parameters with known statistical behavior. Network measurements in different times and with different equipment always bring some variation to the results obtained, which are important to be considered.

III. Quality-Driven Mobility

The quality-based mobility solution proposed is illustrated in Fig. 1. The network information service stores the measured QoS values (and possibly QoE estimates for certain applications) in its spatial database as polygons. Each BS cell can have several polygons, each representing a different quality level. When the signal quality degrades, it starts affecting the QoS through decreased data rates, and increased packet losses and delays. Nevertheless, the traffic load in the BSs of properly designed networks has a bigger impact on the obtainable QoS, which affects all users regardless of their location within cell coverage areas.

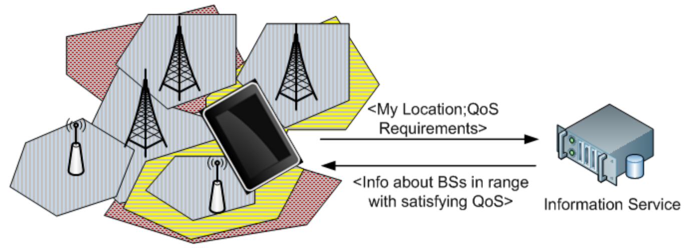

Fig. 1. Information service with QoS coverage areas.

Mobility management entity, residing either in the mobile devices or somewhere in the network, can query the information service for the networks and BSs covering mobile device's current geographical location. In the return message, the information service can indicate the inquirer about the expected QoS the BSs in range can provide. Other information possibly to be requested are, for example, access technology, BS location, frequency band, network address, and capability information. Those and many other information elements that are static in nature are defined, for example, in the standardized IEEE 802.21 MIIS and 3GPP ANDSF. Based on the information returned, the mobility management entity can determine the best possible handover target.

In order to respond to the increased capacity demand, the number of wireless access points is substantially growing. For example, according to CTIA's statistics, there were over 304,000 cell sites in the United States in December 2013, over 2,500 cells more than a year before[1]. Moreover, the Wireless Broadband Alliance predicts that the number of public WLAN hotspots will reach 5.8 million by 2015 worldwide, up a 350% from 2011 [14]. In a dense network infrastructure, the number of overlapping BSs in range can be large, which can translate into large responses if all available information is queried from the network information service. The inquirer can limit the amount of information received by requesting only those information elements it is interested in. Moreover, specifying filters in the query messages is worth considering. For example, the mobile device queries only BSs with certain access technologies, from supported MNOs and with a minimum QoS/QoE value that allows sustaining the adequate service level. The number of queries can also be significant as the number of mobile devices grows substantially, according to Cisco [1] to reach 7 billion in 2013, an 8% increase from 2012. According to [15], the current spatial databases handling polygon geometries can provide a query performance of millions of queries per hour even if there are a million polygons stored. Having a hierarchical information service architecture, like presented [16], [15], where regional information services could store only BS polygons from their respective area can increase the overall query load substantially.

A. Generation and Exploitation of QoS Information

QoS can be determined by a variety of parameters such as packet loss, delay and jitter. Different applications have differ-

[1] http://www.ctia.org/your-wireless-life/how-wireless-works/annual-wireless-industry-survey

ent QoS requirements for providing a satisfactory quality of experience. Some applications are more sensitive to delays and other to packet losses, for example. A variety of application-specific models exist to estimate the quality perceived by the users (perceptual quality is a major factor in QoE). Some of these models are able to perform the estimations based on some application-level parameters and network QoS measurements (e.g. the ITU-T E-Model [17] and PSQA [18]), often in a standard Mean Opinion Score (MOS) scale, 1–5 [19]. This MOS scale is used in our solution to indicate the QoS (or actually QoE estimation) of polygons, because it simplifies the information storing and querying processes compared to a case where delay, jitter and packet loss values are stored separately. This of course presumes that a suitable quality model is available for the applications considered (e.g. voice, video, etc.). In the MOS scale, the value 4 denotes *good* quality and the value 3 (often referred to *toll quality*) is typically the threshold below which users start perceiving quality as unacceptable.

The quality models suitable for the type of usage required by our approach use network QoS metrics (such as delay, jitter and packet losses) to estimate the overall quality perceived by the user. A common problem with QoS-driven mobility has been that those QoS parameters are hard to measure accurately in real-time, especially with active measurement tools. We, however, use Qosmet[2] solution, which is a passive QoS measurement tool. It is able to measure the QoS metrics in real-time for the active applications. Thus, it tells the QoS the used applications achieve in the network, not the QoS of artificial test traffic.

Qosmet is based on light-weight software agents running in measurement points. The agents capture traffic and perform the QoS measurements. Thus, when terminal devices are used in the measurements, the QoS calculation effort is distributed in the network. Measured QoS reflects how the network path affects the application stream. Because of this, a QoS measurement setup needs always two measurement points, which should be located in the end points of the network path of interest. Some protocols, however, can be measured, to some extend, with a single measurement agent, since the protocols themselves carry some information of the measured stream. Such protocols are, e.g., RTP, TCP, and MPEG-TS. With these protocols, the secondary measurement point is, basically, the application node, which generates the traffic. While the good side of this measurement setup is that no extra control traffic is required, the bad side is that only a limited QoS information is available. For example, with RTP, only packet loss and jitter can be measured. A full QoS measurement supporting any application requires two measurement agents in the network. For the one-way delay measurements, clock synchronization is also needed. With modern mobile devices this is not a problem because they are capable of using GPS, that, in addition to knowing their precise geographic location, is able to provide accurate timing. However, an accuracy of microseconds provided by better GPS devices is not required. The goal is not to measure very accurate delays, but rather the problems in the network, which often show up as increased delay levels. Thus, the accuracy in the magnitude of milliseconds for the clock synchronization is sufficient. In fact, also Network Time Protocol (NTP) provides a good enough accuracy in many cases.

[2]http://www.cnl.fi/qosmet.html

If two measurement agents are used for the QoS measurement, the natural location of the primary agent is in the mobile device. The secondary agent should reside in the network side in such location that the user traffic passes through it, to enable packet capturing. As we are now interested in the wireless part performance, the location of the secondary measurement point should be near the access network. One option is that the agents reside directly in the BSs, but as this would require dynamic changing of the secondary agent, when the mobile node moves, this setup is not practical. Thus, mobile operators' Internet gateway node(s) would be a logical choice, for example. Practically all user traffic passes through this point(s). With this setup it can be still assumed that the fixed network part of the whole measured network path has better performance than the wireless part, meaning that the measurement reflects well the wireless part performance. In the two measurement agent case, a small control traffic stream is required between the measurement points in order to enable real-time measurements. This overhead is the cost of this kind of measurement setup. However, the amount of control traffic is only a few percent of the measured application data traffic.

Qosmet measures QoS values, but it also includes PSQA-based quality models for voice and video, making it possible to have real-time estimates of QoE in the MOS scale. It should be also noted that the proposed solution works with any other quality model as long as the scale is the same and their accuracy is of same magnitude. Even though the evaluation of the solution proposed in this paper is based on simulations, the used example measurement component, namely Qosmet, is an existing product, which has been successfully used in a plethora of measurement campaigns in recent years. Moreover, a prototype of the QoS database and a QoS mobility scheme exploiting the database have been implemented. In the prototype, the quality models of Qosmet provide QoE estimations for the user traffic based on the QoS parameters measured real-time. The estimates are stored in the information service database as introduced in the next subsection.

When a mobile device measures the quality of the ongoing services real-time, the results can be utilized locally to monitor the QoS and to trigger handover procedures. However, in the target network selection, real-time QoS information cannot be used because only the active link is measured. If the target cell selection is based on the strongest signal strength, the target cell may not be able to satisfy the service level (e.g. due to congestion) and a new handover is triggered after this is detected. This results in decreased quality for the while until a good connection is found. When the QoS results are available in the information service, the number of handovers to unsatisfying cells can decrease. It is not expected that all mobile devices can measure the QoS for optimized mobility and database updates. For those devices, the information service allows them to also consider the QoS aspect through the cell selection.

Depending on where the entity responsible for mobility decisions reside can affect the target selection. In general, mobile devices try to greedily optimize their quality whereas networks need to handle a bigger picture for load balancing purposes. Mobile device driven mobility can also bring difficulties for

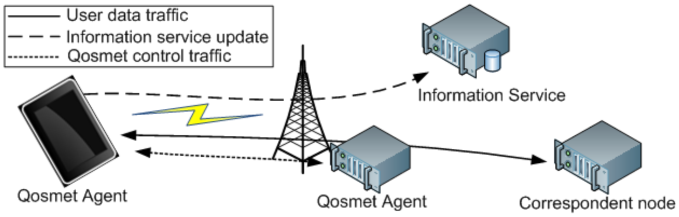

Fig. 2. Update of QoS database.

the cell selection. If multiple nearby devices use the same QoS information for determining the most potential handover target at the same time, the QoS indication returned by the information service may lead to a wrong estimate of what will be the reality when connected. However, for example, mobility policies specified in 3GPP ANDSF can help mitigating this kind of phenomenon. In network-handled mobility management, a large number of simultaneous handovers to the same target BS can be avoided through load balancing rules.

B. Update of the Database

The database must be dynamic in order to reflect the prevailing situation in different locations. The QoS information necessitates frequent updates and due to, e.g., user mobility, its rate of change can be significant. Fig. 2 illustrates the proposed solution for using end systems to measure the QoS and upload the results to the information service. Hence, in the proposed setup, most of the mobile devices not only exploit the QoS database information but also supplement it.

For the end system database updates, an update every 5 seconds or even more infrequently is likely sufficient for public networks. The packet size of update messages is only about a hundred bytes long, depending on the length of the network name and the BS identifier the measurement has taken from. Thus, the extra traffic load caused by the update messages is very low. When the information service is MNO-specific, each MNO maintain their own service, this traffic stays within the network of the MNO measured and it does not burden the outgoing links, which is also the case with the Qosmet control traffic. Our future work with the prototype implementation of the solution will determine the sufficient update frequency and common update data rates in more detail.

As the database updating is dynamic, it can be used also by MNOs to detect device failures in the networks. For example, a BS is observed to be powered up and it responds to Pings from the network side, but the radio side can be malfunctioning; either no traffic goes through or some traffic is transmitted but with a high packet loss ratio. This kind of failure can be quickly noticed based on the QoS measurements.

IV. Evaluation

We evaluated the proposed usage of the QoS enhanced information service in a dense HetNet cell environments with simulations. The evaluation is carried out by using PostgreSQL database of version 9.1.5 with the PostGIS extender (version 2.0.1). The simulation setup is implemented in Perl and use a DBI module as the database interface.

In the simulations, a square measurement area with 20 kilometer (km) side lengths is deployed with different sized

TABLE I. Cell coverage distance ranges

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

TABLE II. Cell type distribution ratios

Ratio	Femto	Pico	Micro	Macro
1	0.05	0.15	0.2	0.6
2	0.1	0.3	0.3	0.3
3	0.2	0.4	0.2	0.2

cells roughly representing realistic femto, pico, micro and macrocells. The simulations do not focus on any specific environment, but the BS locations are randomly selected within the measurement area. The range of the BS cells created is a uniformly distributed random value $R \sim U(R^c_{min}, R^c_{max})$, where R^c_{min} and R^c_{max} are given in Table I for different cell types. The cell type distribution ratios used in the evaluation are given in Table II. The Ratio 1 (R1) includes macrocells the most. In Ratio 2 (R2), the number of different type of cells are quite evenly distributed and Ratio 3 (R3) is mostly composed of small cells. For each BS cell, there was two polygons created and stored in the spatial database. The first polygon covers 90% of the cell range and is assigned with a QoS value, which is a distributed random value based on the probabilities shown in Table III. Scenario 1 (S1) includes a large number of high QoS BSs. In Scenario 2 (S2), 50% of the cells has a QoS of 3. Scenario 3 (S3) is related to a highly congested network environment, where 60% of the cells have a quality value (MOS) of 2 or 1. The polygons are of heptagon shape, which represents a simplified typical wide beamwidth antenna radiation pattern with a random beam direction. Another polygon simulates the impact of signal quality on QoS on the edge of the cell range (last 10% of the range). The first polygon is extended by a polygon having the quality value of the first polygon minus 2.

In the measurement area, a random 20 km long route is traveled and the cell selection is based on the information queried from the information service database. A handover to another BS is performed when the mobile device travels outside the coverage of the currently employed BS, which is known based on the QoS polygons stored in the database. The simulator does not implement any signal propagation model. In a non-optimized case, the nearest cell is selected, which simulates the cell selection based on the traditional strongest signal strength scheme. In QoS-based mobility, the cell with the highest quality value in the mobile device's current location is selected. If multiple BSs with the same quality value exist, the nearest BS is selected. This simulates a mobile device, which is not capable of measuring quality locally but quality is considered only in the cell selection. A QoS-optimized scheme further utilizes the QoS information by constantly monitoring

TABLE III. Quality (MOS) value distributions

Scenario	$QoS = 1$	$QoS = 2$	$QoS = 3$	$QoS = 4$	$QoS = 5$
1	0	0.05	0.15	0.3	0.5
2	0.05	0.2	0.5	0.2	0.05
3	0.35	0.25	0.2	0.15	0.05

TABLE IV. Cell ratio 1 average QoS

Number of cells	Scenario	Non-optimized	QoS-based	QoS-optimized
2000	1	3.95	+12%	+14%
	2	2.75	+5%	+17%
	3	2.13	+12%	+40%
3000	1	3.98	+13%	+15%
	2	2.74	+12%	+24%
	3	2.11	+24%	+54%

TABLE V. Cell ratio 2 average QoS

Number of cells	Scenario	Non-optimized	QoS-based	QoS-optimized
2000	1	3.91	+5%	+9%
	2	2.73	+3%	+14%
	3	2.10	+3%	+28%
3000	1	3.93	+10%	+13%
	2	2.76	+4%	+17%
	3	2.12	+12%	+37%

TABLE VI. Cell ratio 3 average QoS

Number of cells	Scenario	Non-optimized	QoS-based	QoS-optimized
2000	1	3.91	+2%	+6%
	2	2.74	+2%	+11%
	3	2.10	+2%	+21%
3000	1	3.96	+5%	+8%
	2	2.78	+3%	+13%
	3	2.08	+3%	+26%

the current QoS. If the quality in the current cell drops to below 3, better BS options are looked for every 10 meters. Each measurement run was repeated 100 times and for each run a new random measurement area was generated. The results show an average value from the repetitions. The evaluation was carried out with 2,000 and 3,000 BSs in the area.

A. Results

Tables IV, V and VI show the average quality values in relation to the distance traveled with the cell ratios R1, R2 and R3, respectively. Without QoS-based optimization, an average quality value of almost 4 is already obtained in S1, where 80% of the cells has a MOS of 4 or 5. However, when the proportional number of high-quality BSs decreases in the other scenarios, the average quality drops below 3 regardless of whether the measurement area is equipped with 2,000 or 3,000 cells. In R1, the QoS-based cell selection can reach even over 10% improvement in terms of the average QoS on the 20 km route. In R2 and R3, where the proportional number of macrocells is low, the overall gain with 2,000 cells is only in the order of less than 5%. This does not translate into clear quality benefits with many applications. Randomly located 2,000 cells do not constitute a network infrastructure with many overlapping cells all over the measurement area with R2 and R3, which can be seen in the results. With 3,000 cells, an about 10% improvement on the average QoS is observed in S1 and S3 when the cell ratio R2 is used. With R3, the gain is only a few percent, which is not significant.

The QoS-optimized cell selection scheme shows the potential of QoS monitoring for improving the mobility. In S3, where 60% of the cells can provide only quality levels less than or equal to 2, the average quality can be increased significantly. Improvements over 50% higher average quality can be attained with 3,000 cells. With 2,000 cells and R1, almost 40% of all handovers (average 28) in S3 are made to cells with QoS ≥ 4. With 3,000 cells, this number is over 47%. The downside of the QoS-optimized scheme in a small cell environment is that the number of handovers increases, even by 28% in R3 and S3 compared to the non-optimized scheme. This can result in quality degradations, since when a handover is carried out on Layer-3, there is a risk of losing some packets during the handover procedure. Even in novel access technologies, Layer-2 handovers incur additional delay in the magnitude of tens of milliseconds for data flows. For example, in LTE, BS changes can interrupt the network services for up to 80 milliseconds [20]. Thus, the sensitivity for triggering handovers needs to be carefully planned, also to avoid the ping-pong effect between overlapping networks when the QoS is continuously monitored. Overall, the gain with the QoS-optimized scheme with different cell ratios is more pronounced the less high QoS cells are deployed to the measurement area.

Figures 3 and 4 show the proportional improvement of distance traveled with QoS ≥ 4 with 2,000 and 3,000 cells, respectively. The QoS-based and QoS-optimized cell selection schemes are compared with the non-optimized cell selection scheme. When the measurement area includes much macrocells (R1) and the proportion of high quality cells is low (S2 and S3), the QoS-based cell selection scheme provides improvements of over 50% longer distance with QoS ≥ 4 and 2,000 cells. With 3,000 cells, the gain goes over 110%. When the QoS-optimized cell selection is used, the high quality access is used on up to 133% and 220% longer distance with S1, R1, and 2,000 and 3,000 cells in the measurement area, respectively. In S1, where most of the cells can provide high QoS, the improvement of high quality access in relation to the distance traveled is below 20% in the all measurement cases, being with R3 only a few percent. Interestingly, with 2,000 cells in the measurement area, S2 with the QoS-based cell selection scheme provides better results than S3. With 3,000 cells, S3 leads to slightly better results than S2 with R1 and R2. This difference shows the benefit of QoS-based cell selection when the number of overlapping cells increases.

Overall, the QoS-optimized cell selection can clearly outperform the QoS-based selection. This is also expected as in the QoS-based scheme the selected cell is used as long as it can provide access, although the QoS is low. When the number of congested or badly designed networks increases, the QoS-optimized scheme exhibits clear benefits. In practice, the QoS-optimized mobility requires local monitoring of the QoS, which is feasible with the end systems already updating the database. While too-frequent polling of the information service for the QoS monitoring is not reasonable, obtaining the optimal connectivity requires finding a good balance between minimizing the frequency of querying and optimizing the handover decision algorithms.

V. Conclusion

Network information services can help end-users improve the mobility in HetNets by providing information about networks and BSs for cell selection. However, currently there is no solution to discover the expected QoS/QoE in the target networks prior to connecting to them. We presented an enhancement to current information services allowing to store quality data (both QoS measurements and QoE estimates)

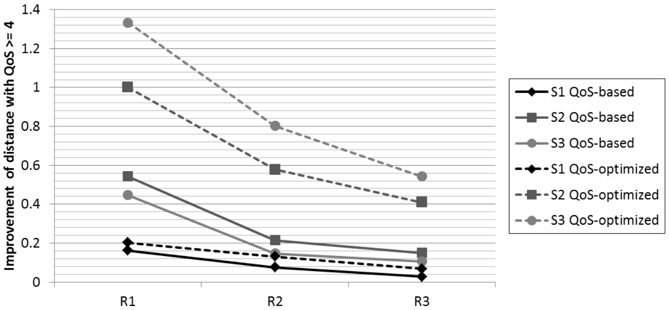

Fig. 3. Proportional improvement of distance with QoS ≥ 4 and 2000 cells.

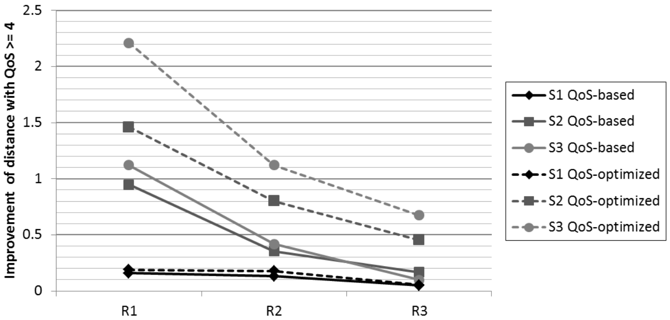

Fig. 4. Proportional improvement of distance with QoS ≥ 4 and 3000 cells.

based on end system performed measurements. The QoS in different areas is represented as polygon geometries and mobile devices can query for the handover target candidates and their QoS in their current location to facilitate cell selection. We evaluated such solution with simulations using different HetNet infrastructures and quality distribution scenarios. We found that the average perceived quality can be improved even by tens of percent through the QoS-based cell selection scheme. However, optimizing the mobility through frequent querying or when the mobile device is capable of monitoring the QoS locally was observed to be even more helpful, resulting in even over 50% higher average quality. Also MNOs can benefit from the database by finding the problem areas in their networks easily. The next step is to use our prototype implementation of the solution to collect an extensive database for hands-on mobility tests and database updating. One of the open research topics is to study how sliding window and moving averaging techniques should be used for the measurement data in order to dynamically modify the QoS polygons to reflect the prevailing situation best.

The solution proposed does not bring new capacity to networks. If a network does not provide sufficient resources for the users, the overall QoS will be in any case bad. Thus, there are still needs to equip networks with more resources to keep up with increasing data traffic demands. However, the solution helps better utilizing the existing resources; coverage gaps, congested cells, and cells with malfunctioning equipment can be avoided, and traffic load balancing in networks enhanced.

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