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Energy Efficient Mobility Enhancement in LTE Pico–Macro HetNet Systems

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Abstract

Mobility management plays an important role in heterogeneous networks (HetNets), because it helps to reduce radio link failures, handover delays, and power consumption, and enhances offloading benefits. In the present study, two cases are identified regarding mobility in HetNets. The first one is related to signaling and the second one is related to data transmission; i.e., handover and link rate adaptation. It has been shown that both processes are affected by the user mobility level and that performance deteriorates near cell edges. The aim is to optimize the user offloading to picocells depending on their estimated speeds so that overall system performance is maximized. The network-centric solution and cooperation between cells that achieve seamless handover is presented, and the impact of the performed measurements for link adaptation during motion is investigated.

Keywords DRX · Handover · HetNet · LTE · Link adaptation

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1 Introduction

The evolution in LTE network topology enhances radio link performance and spectrum efficiency as the fifth generation (5G) networks move toward HetNets. One of the main incentives for the use of HetNets is the increase in capacity, and the enhancement of the coverage of the LTE system [1]. Small cells, such as picocells, are deployed at the macrocell boundaries to improve possibly weak coverage that occurs for several reasons, such as path loss and fading. Picocells are also deployed within the macrocell coverage, in hotspots, to increase the possibility of traffic offloading from larger cells to smaller ones [2, 3].

In the future 5G networks, procedures such as handover and cell reselection are becoming more complex due to the dense deployment of different types of cells and the issues of mobility performance between large and small cells in different environmental conditions. Due to the inherent delay, and therefore non-optimal selected parameters, the performance of heterogeneous networks could undergo high potential degradation if mobility robustness and handover issues are not considered in HetNets compared to macro-only network scenarios [4].

While mobility in a wireless network has an impact on the handover process, and may cause radio link failure and delays, another challenge is the effect of mobility on the link quality; i.e. link adaptation during connection and data transmission.

Seamless and robust mobility, in addition to handover issues in HetNets, are under consideration for LTE-Advanced in order to reduce delay and packet loss during handover [5]. Mobility enhancements presented in this study have been developed based on the mobility issues addressed in the 3GPP technical report [6, 7]. This report presents the effects of discontinuous reception (DRX) long cycle on the handover at different motion speeds and the results show that a long sleeping period, when the user equipment (UE) switches off the transceiver circuit, causes more radio link failures at higher speeds. The studied speeds are 30, 60 and 120 kmph representing low, medium, and high speeds, respectively.

The cell size and location information are useful for the estimation of the mobility level in the HetNet and this information is made available and accessible through the mobility management entity (MME). In location-based services, there exist various proposals on how to calculate the location of the subscriber; however, these proposals differ in accuracy and complexity. One method is based on additional radio measurements after the UE establishes a radio connection [8]. The distance is estimated by measuring the reference signal received power (RSRP), timing advance, time of arrival and the round trip time [9]. RSRP fingerprint match has been proposed earlier in [10] in order to guide the UE to hand over to the small cell locations. In [11] the small cell fingerprint is used to identify the presence of small cells in the network and the mobility level is estimated by considering the number of handovers in a time period (in seconds). However, it does not consider that the cell size and the mobility state (low, medium or high) is not estimated accurately. Therefore, the mobility approach in HetNets should be different from that in macro-only networks because the mobility state estimation (MSE) is not as accurate in HetNets as in a purely macro environment due to different cell sizes. In this study, the UEs proximity to the picocell is detected through location services. Further use of location services is made to estimate the mobility level, where the macrocell estimates the location of the UE through the positioning functions implemented in the eNB. Therefore, enhancements have been introduced in addition to the actions taken to provide seamless handover between cells, and then the effects of mobility on the link quality during connection and data transmission are considered. The geo-location service is considered to support picocell discovery as well as seamless and robust mobility of mobile devices between macro and picocells in LTE HetNets. Furthermore, the effects of the measurement window size on link quality have been studied in some detail.

1.1 Mobility Issues and Radio Link Failures

By deploying a large number of picocells, the site density increases and, consequently, the handover rates increase because the number of handovers is inversely proportional to the cell size. High handover rates imply an increase in the signaling load, and this has an adverse impact on the terminal throughput because there is no data transmission during the handover period. In HetNets, the inter-layer radio resource management is time consuming when the cell selection process is performed frequently. Furthermore, the radio link failures increase due to failures in the handover process [12].

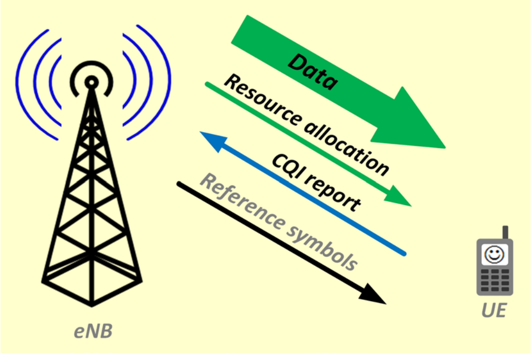
A radio link failure may occur by performing handover at unsuitable times, i.e., early or late handover triggers. The network should have a fast dynamic response to decide to hand over to a picocell or macrocell or to delay handover for a certain period of time. This dynamic response depends on the UEs position in the macrocell, especially at the cell boundaries where the performance undergoes degradation.

When the UE is connected to the serving macrocell, and if the UE is in a high mobility state, it has to trigger handover after a short period when a better cell is discovered. The fast moving UE passes the handover region quickly; therefore the handover region is not large enough for the UE to complete the handover successfully within this area. The signal from the serving cell is weak, so the UE does not receive the handover command due to physical downlink control channel (PDCCH) outage. The UE leaves the cell coverage area before the handover is complete, and as a result it is not able to continue communicating with the macrocell because its signal is lower than the minimum threshold. It is also not able to connect to the picocell because handover is not completed and this fact will cause a handover failure.

1.2 Mobility Level and Link Adaptation

In the link adaptation process of LTE systems shown in Fig. 1, a measurement window is defined (in milliseconds) in order to have a relevant measure of the link quality. The SINR is computed from observations within this measurement window. The UE takes radio measurements of the current SINR and these measurements are reported continuously to

Fig. 1 Link adaptation in LTE



the serving cell in the form of a channel quality indicator (CQI), which in turn determines a suitable operating modulation and coding scheme (MCS) for the link. Each UE records instantaneous values of SINR and smooths them using a measurement window. The size of the measurement window is controlled and reconfigured by setting the link adaptation parameters reported by the serving eNB.

Mobility has a major impact on the channel condition measurements and the utilization of the data channel. This delays the channel feedback process reported by the UEs to the serving eNB. The reported CQI value on the uplink and its corresponding MCS for one location may not be suitable at another location and may also differ among small and large cells. The channel estimation and reporting are delay-sensitive and the reported SINR values may be different from the actual values that occurred prior to the uplink transmission. Until the throughput is recovered and the CQI value is reported, there will be Hybrid Automatic Repeat Request (HARQ) delays and higher retransmissions rates over the wireless link due to the sharp decrease in the node throughput. A long measurement window gives the UE the time to make reliable measurements. However, at mobility, the reporting delays are a serious concern because they cause ageing of the measurements due to the fast-varying channel. Moreover, the use of picocells configured with a long measurement window size at the macrocell boundaries has remarkable effects. The UE performs link adaptation while it is connected to picocells where the SINR is good because a picocell has a small coverage with a good RSRP signal strength. However, due to mobility it moves to connect to the macrocell where the SINR changes. When a longer measurement window size is used with mobility, the measured signal strength and quality become old values because of sudden channel variations, thus resulting in measurement errors and reporting delays. This issue is addressed when investigating mobility, and efficiency is increased by updating the link adaptation parameters according to mobility levels and acquiring a new CQI report in order to avoid degradation in throughput and poor performance.

2 Improved Small Cell Discovery and Handover

Two issues are addressed with picocells. The first one is that the UE needs to find the picocell to offload data but in some situations it is not aware whether the picocell is available, therefore it has to perform inter-frequency measurements. The second issue is for how long the UE will camp under the newly discovered picocell.

It is important to investigate better strategies to identify and evaluate the candidate cells, and improve handover performance. The proposed actions imply that picocells are avoided in high speed UEs for two reasons, the first of which is UE instability. High mobility triggers large numbers of handovers with a short time of stay, and subsequently the UE has to start new measurements in order to find a new cell. This degrades the UE performance when it passes across a large number of cells and causes significant radio link failures, especially when the cells have small coverage areas, through which the UE can pass quickly after connecting. It will then restart the attach procedure with another cell. The second reason is to avoid instantaneous changes in the load of the small cell. High speed UEs are allocated to a macrocell prune list and will be excluded from handover to picocells and therefore will only hand over to macrocells. Because the UE is suspended from handing over to picocells, the measurements are made less frequently. These less frequent measurements enable the UE to avoid the overhead of handovers to smaller cells and the ping-pong states among them.

The prune list contains only the macrocells connected to the Evolved Packet Core (EPC) (macro-only scenario) and it is allocated through setting the configuration on each macrocell. The macrocell contacts the MME to obtain its list of neighbour macrocells. Close to the macrocell boundaries, the link quality suffers from shadowing and fading and here the macrocell issues a measurement gap for the UE to start searching for new macrocells (Fig. 2). Although the high speed UEs are suspended from handing over to picocells, the network offloading will not be seriously affected because that procedure is only applied to high-speed UEs.

On the other hand, in medium and low mobility levels, the UE has to make the best use of offloading to picocells so that the majority of the handovers should go to the deployed picocells. Therefore, enhancement is focused on detecting picocells efficiently. In HetNets, the UE may not be aware of the availability of picocells, so it has to keep performing measurements, which is not efficient for its power consumption. Therefore, the power consumption is higher at low mobility levels due to picocell detection. Moreover, the power consumption is higher when the picocells are operating on different carrier frequencies to those of the UE, and thus the discovery of the picocells could take a longer time if they operate in an on/off mode.

The UE has to be aware of the picocells presence before it starts the measurement. The proposed solution is that the serving cell indicates the picocells existence through the measurement-reporting configuration, or, if it is possible, the serving cell broadcasts this indication. This solution aims to optimize the cell search and selection during motion and ensure that the UE will not start a cell search and will not connect to a picocell until it is close to this picocell. In this way, the UE saves time and does not need to spend power on measuring the surrounding environment. When the UE starts to approach a picocell, the macrocell triggers measurement reporting to the UE and the UE starts to generate reports to perform handover (Fig. 2). If the macrocell provides information about the picocell band, the cell search and measurement will significantly improve.

Through network guidance, network offloading is guaranteed in low and medium mobility levels, thus helping to reduce the effects of the dynamic nature of traffic within the picocell. In this way, the reference signals (RS) and control signals transmitted by

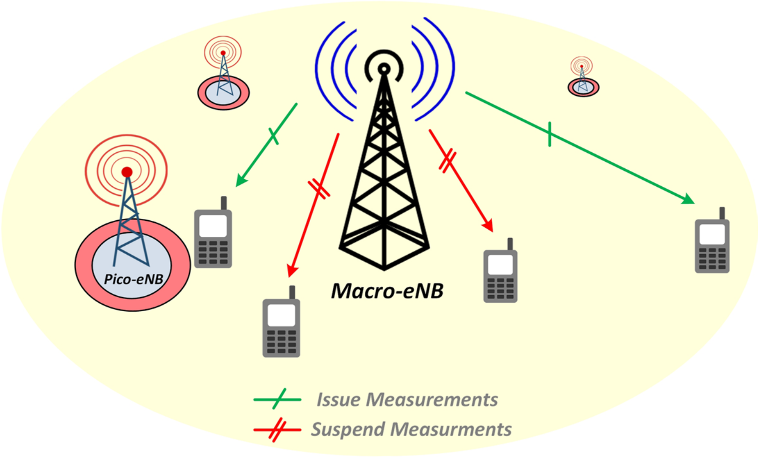


Fig. 2 Macrocell issues/suspends measurements

the picocells are reduced, alleviating the interference resulting from these signals. The macrocell contacts the MME to update its records about the presence and location of the picocells. If the picocell has a low number of UEs, the macrocell may not guide the UE to that picocell and this cell could be turned off to save energy in an on/off mechanism.

Due to the difference between the high RSRP of the serving picocell and the low RSRP of the macrocell at the picocell boundaries, the picocell-to-macrocell handover is triggered when the measured RSRP of the picocell becomes lower than that of the macrocell. The picocell will not start the handover procedure until the handover criteria meet the macrocell selection threshold (Fig. 3), which is the minimum required RSRP for eNB, as defined by the operator. The value of this threshold can be obtained directly by the picocell through X2 negotiation or through decoding the macrocells downlink signal [13].

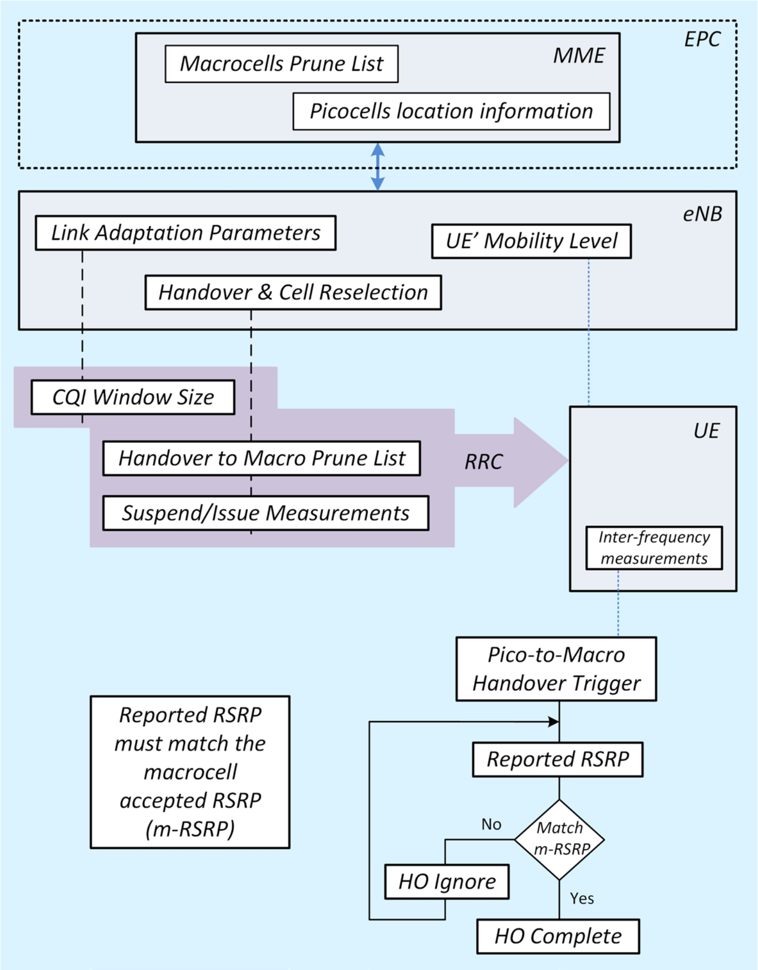


Fig. 3 HetNet mobility main framework

3 System Implementation

OPNET 18.0 is used to model all handover features including neighbour advertisements, scanning, dynamic selection and many others. Also, the link rate adaptation and location services are available and modelled according to the 3GPP standards within the OPNET LTE model. In the simulated scenarios, all the cells are interconnected with the EPC.

The picocell distribution used is adopted from the 3GPP standard [6]. UE placement and trajectories are defined for mobility and simulation calibration as follows: one trajectory is at the cell boundary and the other is inside the cell, but both trajectories traverse across multiple cells in order to receive different strength signals during motion. Some picocells could be in a good position for handover, while others might be in an unsuitable position. The UEs are randomly placed in the simulation area and they are allowed to move at one of three randomly selected speeds, i.e., 30 kmph, 60 kmph or 120 kmph. An IP flow is created between every UE and the server to maintain resource utilization and data connectivity during motion.

4 Results and Discussion

The simulation results are compared to those acquired from normal HetNets and macro-only scenarios (when the UE is connected to the macrocell prune list). Power consumption is investigated since it is one of the key challenges in the next generation of mobile multimedia networks. The adverse effect of the large number of connections established, and multiple handovers in HetNets, are presented through the DRX timing statistics and modes. The mode is said to be normal when the UE is in normal operation, transmitting and receiving. The mode is said to be active when the UE is just listening to the eNBs downlink control channel to check if there is a data dedicated for it. Finally, the sleep mode—the power saving mode occurs when the UE switches off its transceiver and it is neither receiving nor transmitting. Figure 4 shows the operating time spent in normal, active and sleep modes. In the normal HetNet scenario, due to its fast motion, the UE performs the measurements more frequently because it passes through the cells rapidly. These measurements continuously interrupt the sleep period of the DRX. In the proposed scenario, the measurements are made less frequently because the high speed UE is forced to connect only to the macrocells. According to this figure, the sleep period is almost double the period of the normal HetNet scenario, which results in a longer life for the UEs battery.

In low and medium-speed mobility, the improved cell search through network guidance has a positive impact on power consumption as the UE saves a considerable amount of power. The saving in the operating power is related to the low number of triggered measurement gaps. The measurement gap is 6 ms long [14] and the power consumption of the device, as defined in our model for normal operation, is 0.1 W. Thus the approximate power consumed on a measurement event is $32{,}844 \times 1.667 \times 10^{-4}$ mWh. For example, over 1 h of simulation for the two scenarios, as shown in Table 1, the decrease in the number of measurement events is 32,844 events, and the corresponding decrease in the operating power is $32{,}844 \times 1.667 \times 10^{-4}$ which is around 5.5 mWh and this is approximately 49% of the UE total saved power of 11.20 mWh. Therefore, in the low mobility scenario, a considerable amount of UE power is saved due to the reduction in the number of measurement gap events.

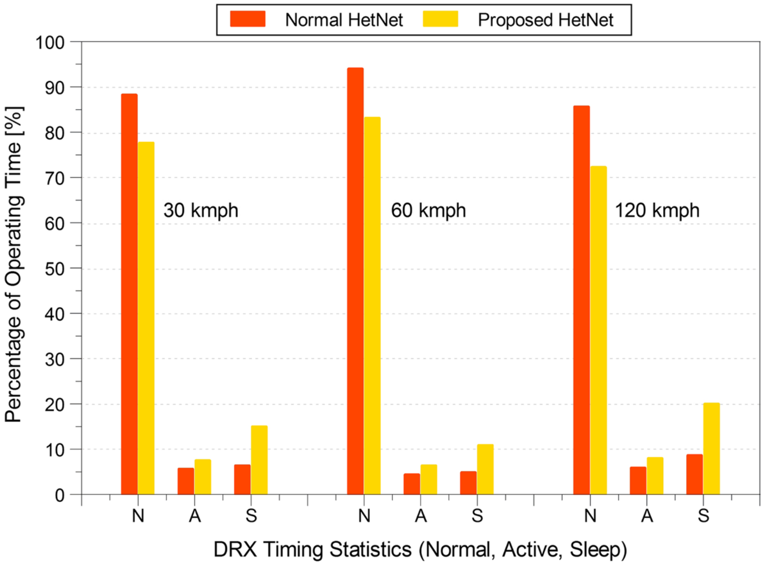


Fig. 4 DRX timing comparison

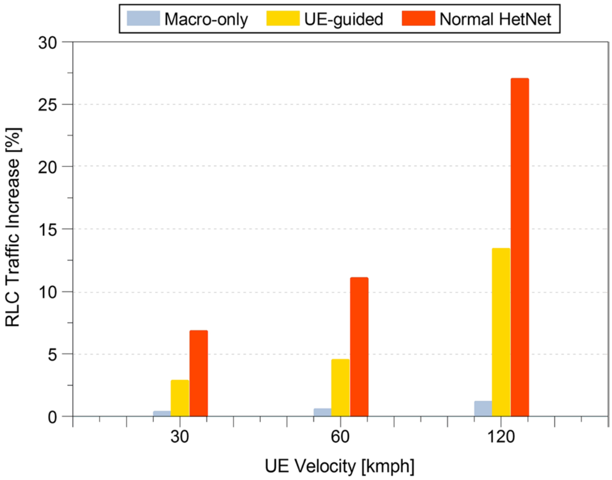
Table 1 Measurement events and UEs power consumption

	No. of measurement events	UE total power consumption (mWh)
Normal HetNet	94,850	105.25
Proposed HetNet	62,006	94.05
Savings	32,844	11.20

In order to investigate the overhead of the mobility management frame, radio link control (RLC) traffic is presented. This statistic represents the uplink LTE RLC sublayer traffic sent by the UE to the serving cell and it includes the overhead due to the RLC headers, in addition to the retransmitted traffic and status report traffic. Figure 5 shows the percentage of RLC traffic increase of the connected UE. The percentage is compared to the 3.6 kmph scenario, which is the normal mobility level of a walking user. The figure displays the comparative results of three cases which respectively concern (1) the macro network only, (2) the proposed HetNet scheme, where the UE is guided to find the picocell and (3) the normal HetNet when the UE performs continuous measurements to find the picocell. From this figure, it is obvious that the UE RLC sublayer has to deal with more traffic when the mobility level increases. In the case of a high-mobility state of 120 kmph it is more efficient to suspend the handover to the picocells and stay with the macrocell in order to avoid overheads.

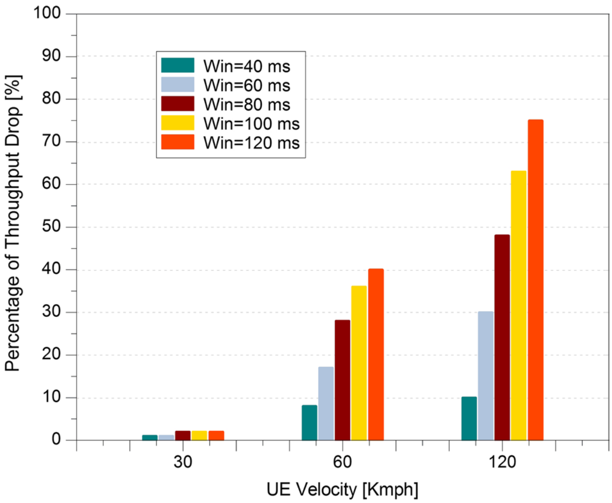
The effects of mobility on measurements and link adaptation parameters are revealed by investigating the effects of the measurement window size during different mobility states. Reporting delay causes instantaneous drops in the throughput and sometimes the drops are sharp and the throughput decreases by a large percentage before it recovers and then the drops occur repeatedly. The maximum percentage of instant cell edge throughput drops

Fig. 5 RLC overhead



among different mobility levels is demonstrated in Fig. 6 for different values of measurement window size. The adverse effects of using long measurement windows at high mobility levels appear clearly on the UEs received throughput due to ageing of the reported measurements. On the other hand, the figure indicates that at low speeds, the measurement window size has a minor effect on the transmission because the UE has enough time to perform measurements and report the link condition. Depending on the link condition and the position of the UE in the cell, the effects of high-speed mobility can deteriorate and this is due to inaccuracy and errors in the SINR measurement process, in addition to the errors occurring in the quantization of the SINR values; there is also a delay between performing the measurement and the actual data transmissions. Link failures and retransmissions at distances far from the cell centre result in delays in updating and reporting the link parameters.

Fig. 6 Throughput drop at cell edge



5 Conclusions

In this study, it has been shown that keeping the same parameter configurations with different mobility levels in HetNets is not an efficient solution. This is due to potential failures in handover commands and ageing of the reported parameters. Furthermore, there is a need for an effective approach to accurately localize the mobile devices within the network. In this regard, the proposed method leads to enhanced cooperation between the macrocell and the underlying picocells. In this way, the mobility performance indicators are improved, including the consumed power from the UEs battery, the instantaneous throughput degradation, and the reduction of the overhead of signaling while connecting to a large number of cells during motion.

On the other hand, link adaptation is a vital process for data transmission in the LTE system. However, at medium to high speeds, link adaptation can potentially have an adverse impact on the received traffic, especially in the case where the UE performs channel measurements using a long window size. Therefore, network operators need to optimize and consider the impact of the set link adaptation parameters, especially at the cell boundaries.

References

1. Zhang, H., et al. (2015). 5G wireless network: MyNET and SONAC. *IEEE Network*, *29*, 14–23.
2. TR 32.835 LTE; study of heterogeneous networks management 3GPP, June (2014).
3. Wang, P., et al. (2015). QoS-aware cell association in 5G heterogeneous networks with massive MIMO. *IEEE Network*, *29*, 76–82.
4. Ge, X., et al. (2014). 5G wireless backhaul networks: Challenges and research advances. *IEEE Network*, *28*, 6–11.
5. TR 136 912, LTE; feasibility study for further advancements for E-UTRA (LTE-Advanced), 3GPP (2017).
6. TR 36.839, Technical specification group radio access network; evolved universal terrestrial radio access (E-UTRA); mobility enhancements in heterogeneous networks, 3GPP (2012).
7. ETSI TR 136 932, Scenarios and requirements for small cell enhancements for E-UTRA and E-UTRAN 3GPP (2017).
8. Huawei, HiSilicon discussion on network assistance signalling for small cell discovery, 3GPP TSG RAN, August (2015).
9. Cherian, S. S., & Rudrapatna, A. N. (2013). LTE location technologies and delivery solutions. *Bell Labs Technical Journal*, *18*(2), 175–194.
10. China Academy of Telecommunications Technology CATT discussion on small cell discovery, 3GPP TSG RAN, February (2014).
11. Prasad, A., Tirkkonen, O., Lundn, P., Yilmaz, O. N. C., Dalsgaard, L., & Wijting, C. (2013). Energy-efficient inter-frequency small cell discovery techniques for LTE-advanced heterogeneous network deployments. *IEEE Communications Magazine*, *51*(5), 72–81.
12. Lorca, J., & Sierra, A. (2013). A simple speed estimation algorithm for mobility-aware SON RRM strategies in LTE. In *Proceedings of wireless days (WD), IFIP, 2013* (pp. 1–3).
13. Lee, C., & Kim, J. (2013). System information acquisition schemes for fast scanning of femtocells in 3GPP LTE networks. *IEEE Communications Letters*, *17*, 131–134.
14. ETSI TS 136 133, LTE; evolved universal terrestrial radio access (E-UTRA); requirements for support of radio resource management, 3GPP (2017).

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