Performance of Hard Handover in 5G Heterogeneous Networks

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***Abstract*—To satisfy the high data demands in future cellular networks, an ultra-densification approach is introduced to shrink the coverage of base station (BS) and improve the frequency reuse. In an ultra-densification approach, small cells such as relay node (RN), micro, pico and femto base stations (BSs) are deployed to the network of macro cells in the same geographic region, forming HetNet. HetNets introduce some notable challenges like inter-cell-interference-coordination (ICIC), mobility management and backhaul provisioning. In this paper, we investigate the performance of the hard handover (HHO) in 5G HetNets. The performance metrics are the total number of handovers and the outage probability. Simulation results show that the average outage probability is decreased in HetNet scenario compared the macro only scenario. However, this improvement comes at the expense of increase number of handovers.**

***Keywords*—-Hard Handover; 5G; Relay Node (RN); HetNets; Ultra Densification**

I. Introduction

There has been an exponential growth in mobile data usage over the last 15 years (over 400 million fold) that is expected to go up nearly 6-fold between 2017/2022 [1, 2]. The number of cellular broadband subscribers will increase to 8.3 billion in 2022 [3, 4] and the network's data traffic is expected to reach 351 Exabyte by 2025 [5, 6, 7]. Moreover, 5G networks are expected to provide approximately a system capacity 1000 times higher, 10 times the data rates, 25 times the average cell throughput and 5 times reduced latency when compared to the 4G networks [6, 8, 9]. A key approach supported by 5G is ultra-cell-densification to satisfy the high data traffic demands and service requirements [1]. In ultra-cell-densification, low cost of small cells attracts operators to deploy to the network of macro cells in the same geographic region, forming HetNet. HetNets are comprised of different types of small cells with different capabilities. These include remote radio head (RRH), relay node (RN), micro cell, Pico cell and femto cell [10, 11].

The introduction of small cells in HetNets has the potential to improve the coverage, to scale the system capacity to users significantly and to provide uninterrupted high-rate communication services to users more reliably. However, deployment of these small cells can result in increased interference and high energy consumption of the network, too frequent HOs, unnecessary HOs with ping-pong (PP) (back and forth HO) effect, handover failure (HOF) and increased delay. If a device undergoes multiple HO, the HO delay will be accumulate resulting in a severe deterioration to the user experience [1, 3, 12].

To meet the 5G targets, mobility management will play an important role, especially in successfully realizing small cell deployments, with its foreseen capacity boost while challenging radio dynamics; but also noting that the demand of mobile services on-the-move is increasing with the appearance of new mobility paradigms such as self-driving vehicles, drones, and mobile small cells [13]. Extensive studies have been conducted in the literature to overcome management problems in HetNets. Details on these studies can be found in [1, 3, 14]. Mobility mechanism causes dynamic variation in link quality and interference levels in cellular systems, sometimes requiring that a particular user changes its serving station to ensure the continuity of the communication service. This change is known as a handover. Handover process is a core element of cellular network to support mobility [31]. The main target of handover is to provide a continuous connection when a user equipment (UE) migrates from the air-interface of one cell to the air-interface provided by another cell. In homogeneous network deployments, UEs use the same set of HO parameters (such as time to trigger (TTT) and hysteresis margin (HM)) throughout the network. In addition, handover occurs from the current serving macro BS in one cell to the target macro BS in another cell or between different sectors of the same cell. However, HetNets contains a macro BS in addition to small cells. The introduction of small cells in HetNets creates additional handover scenarios and increases the number of handovers. In fact, in HetNets additional handovers occur between macro cells and small cells or between two different small cells that can be within the same or different cells. However, using the same set of parameters in HetNets would degrade mobility performance as noted in [15].

This paper is organized as follows. A detailed overview of HO management in 5G network is presented in section II. Section III describes the simulation model. The simulation results are analyzed and discussed in section IV. Finally, section V concludes the paper.

II. HANDOVER IN 5G NETWORK

Providing mobility robustness and reducing service interruption are key challenges in 5G new radio (NR). A NG Radio Access Network (NG-RAN) node can be either a gNB or an ng-eNB. A gNB offers NR user plane and control plane protocol terminations towards the UE. On the other hand, E-UTRAN user plane and control plane protocol terminations towards the UE is provided by an ng-eNB node. The gNBs and ng-eNBs are interconnected by means of Xn interface whereas the connection between gNB/ng-eNB and the NR core network is made using NG interface. More specifically, the connection of gNBs/ng-eNBs to the Access and Mobility Management Function (AMF) and to the User Plane Function (UPF) are defined by means of NG-C interface and NG-U interface, respectively. In 5G NR, the following HO types can be defined:

- **Intra-gNB HO:** In this type of HO, both the source cell and target cell are located in the same gNB. This types includes HO between macro BS and small BS or between small BSs in the same cell.
- **Inter-gNB intra-AMF HO:** In this type, both the source cell and target cell are located in different gNBs. This particular case is an intra-AMF wherein the AMF is not changed as a consequence of the HO. This type includes HOs between macro BS in one cell and macro/small BS in another cell or between small BSs in different cells.
- **Inter-gNB HO with AMF Change:** This type of HO includes a change of AMF via signaling messages exchanges between the source and target AMFs over the NG14 interface. This type similarly includes HOs between macro BS in one cell and macro/small BS in another cell or between small BSs in different cells.

In 4G and 5G technologies, the HO process is a break-before-make hard handover (HHO) scheme, with a large number of densely deployed BSs than the preceding network technologies. HHO refers to the situation when a UE communicates with only one station at a time. In HHO, the connection with the serving BS (S-BS) is momentarily broken before a new connection is made towards the target BS (T-BS). In 5G NR cellular networks, UE-assisted network-controlled handovers are implemented [16]; wherein the serving gNB decides to move the UE from one cell to another based on the measurement report (MR) received from the UE. The basic HO procedure in 5G NR (which is similar to LTE HO procedure), containing three phases: handover preparation (HOP) phase (steps 1 - 3), handover execution (HOE) phase (steps 4 - 7) and HO completion phase (steps 8 - 11) [1, 31]:

A. Handover Preparation (HOP) Phase

The following steps are performed in the HOP phase:

- **Step 1:** The downlink signal strength is continually measured by the UEs and the MR is sent to the serving gNB.
- **Step 2:** According to the MR and radio resource management (RRM) information, a HO decision is made by the serving gNB which transmits a HO_ Request message to the target gNB.
- **Step 3:** If the target gNB can grant resources, it performs admission control procedure, and transmits a HO_Request_Acknowledgement to the serving gNB.

B. Handover Execution (HOE) Phase

The following steps are performed in the HOE phase:

- **Step 4:** Once the HO_ Request_Acknowledgement message is received, the serving gNB may initiate data forwarding.
- **Step 5:** a HO command is issued to the UE by the serving gNB.
- **Step 6:** The SN Status Transfer message is transmitted by the serving gNB to the target gNB.
- **Step 7:** UE detaches from the old serving gNB and synchronizes with the target gNB.

C. HO Completion Phase

In handover completion phase, the following steps are performed:

- **Step 8:** Through the message Path Switch Request sent by the target gNB, the AMF is informed that UE has switched the cell.
- **Step 9:** Thus, the future DL data path will be changed towards the target side by NR core.
- **Step 10:** The Path_Switch_Request message is acknowledged by the AMF.
- **Step 11:** At this stage, the target gNB communicates with the serving gNB to report the success of HO procedure. Finally, the serving gNB releases the radio resources it allocated to the UE.

For modeling, the HO processing of an UE is also divided into 3 states [10, 17]:

- **State 1:** Before the A3 event handover criteria is fulfilled.
- **State 2:** After the handover criteria is fulfilled but before the handover command is successfully received by the UE.
- **State 3:** After the HO command is received by the UE, but before the HO process is successfully accomplished.

The UE estimates the reference signal received power (RSRP) every 40 ms and makes linear average over 5 consecutive RSRP samples [18, 19]. Consequently, the handover measurement period for an UE in L3 is 200 ms. Event A3 occurs when the L3 filtered RSRP of the target cell is higher than the RSRP of current serving cell plus A3 offset or hysteresis margin for time-to-trigger (TTT) period, and the trigger condition can be expressed as [10, 14, 20]:

Event A3: $RSRP_T > RSRP_S + Offset$ (1)

where $RSRP_S$ is the average RSRP of the current serving macro BS/small BS, $RSRP_T$ is the average RSRP of the target macro BS/small BS, and $Offset$ is the A3 offset or hysteresis margin (HM).

III. Simulation Model

A. Network Model

The performance of the HHO is evaluated using a system level simulation developed in MATLAB. We consider the downlink (DL) transmissions in interference-limited 5G HetNets that consists of seven hexagonal cells with a wrap-around structure [21]. 12 fixed RNs are added to the conventional macro cellular networks which has one BS located at the center of each cell as shown in Fig. 1. In Each cell, 6 RNs are located at 2/3rd on the line that connects the center of the cell to one of the six cell vertices between BS and cell boundary whereas another 6 RNs are located at 2/3rd on the line that connects the center of the cell to the middle of each hexagon's side. It is assumed that the RN is in-band layer 3 relay that demodulates and decodes the received signal and re-modulates and re-encodes the signal before its transmission [22]. In in-band relaying, the access and backhaul (relay) links operate in the same carrier frequency. The separation between the access and backhaul transmissions is done using time division approach [23]. 30 UEs are uniformly distributed throughout each cell and in each frame the UEs move along a random direction selected using the modified random direction mobility model. The initial direction of each UE is generated randomly by the uniform distribution in the range [0, 360] degrees. The new direction of each UE is selected randomly in the range [$-45, 45$] degrees related to the preceding direction [24]. Meanwhile, the full-buffer traffic model is considered wherein each UE always has data to send or receive in the buffer [25]. Each user is allocated one physical resource block (PRB), which is defined as a set of 12 sub-carriers and each subcarrier is 15kHz. The HHO algorithm is implemented as described in section II [10, 14]. The simulation parameters are listed in Table I [10, 32]. In this simulation, two scenarios are evaluated and compared; namely HetNet scenario 1 that uses one macro BS and 12 RNs at each cell and macro only scenario 2 that uses only one macro BS at each cell.

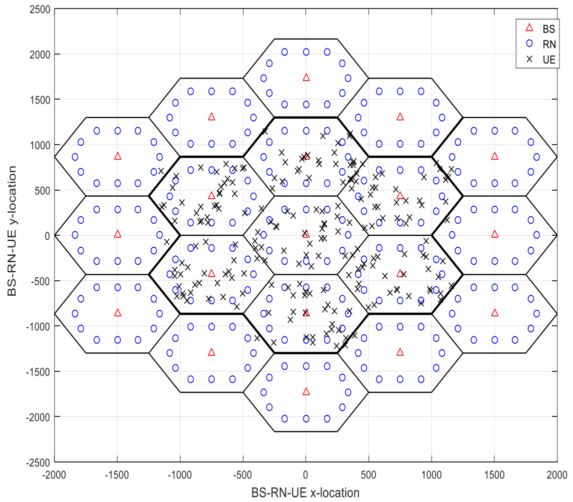

Fig. 1. Simulated cellular layout

TABLE I. Simulation Parameters

Parameter	Value
Cell radius	500m
Carrier frequency	3.5 MHz
Channel bandwidth	10 MHz
FFT size	1024
UE distribution	Uniform random distribution in the simulation area
HHO A3 offset	3 dB
A3 TTT	160 ms
Transmitted power	BS: 46 dBm, RN: 33 dBm
Shadowing standard deviation	Access links: 10 dB, Relay links: 4 dB
Shadowing de-correlation distance	25 m
Antenna heights	BS: 30 m, RN: 15m, UE: 1.5m
Antenna gain	BS: 15 dB, RN: 12 dB, UE: 0 dB
UE speed	3, 30, 60, 120 km/hr
Traffic model	Full buffer
Noise figure	BS/RN: 5 dB, UE: 9 dB

B. Propagation Model

In our simulation, cells considered are macro and small cells in an urban area. The backhaul link between the BS and RN is assumed to be reliable and in line of sight (LOS), while the access links between the BS and UE and between RN and UE are in non LOS (NLOS). The WINNER II (Type C2) path loss model is considered for both macro and small cell [28, 29] as follows:

$$PL = [44.9 - 6.55\log_{10}(h_{BS})]\log_{10}(d) + 26.46 + 5.83\log_{10}(h_{BS}) + 20\log_{10}\left(\frac{f[GHz]}{2}\right) \quad (2)$$

Where d is the distance (in meter) between the BS/RN transmitter and UE receiver with $50m < d < 5km.$, h_{BS} is the BS/RN antenna height, f is the frequency of operation in GHz with $2GHz \le f \le 6GHz$.

Large-scale shadow fading is modelled as a lognormal random variable with zero mean and standard deviations of 10 dB for the access links and 4 dB for the backhaul links. The temporal correlation of the shadowing is modeled with a decorrelation distance of 25 m.

C. Modeling of the Average DL SINR

It is assumed that all sub-carriers are allocated in every cell at the same time. The average DL SINR of each sub-carrier for a HHO user can be written as:

$$\bar{\gamma}_{j,k}^{HHO} = \frac{P_{s,k}^{j}}{\sum_{i \in \Phi_i} I_{i,k}^{j} + P_N} \quad (3)$$

where $P_{s,k}^{j}$ is the received power of sub-carrier j having taken into account the path loss and shadow fading between the serving station and the destination terminal, $I_{i,k}^{j}$ is the average interference caused by the cell i to user k at sub-carrier j, the subscripts s and i stand for the serving cell and the interfering cell, respectively, Φ_i is the set of interfering cells and P_N is the receiver noise:

D. Outage Probability

The outage probability is defined as the probability that the average DL SINR $(\bar{\gamma})$ does not meet the minimum SINR requirement for the receiver to obtain services $(\bar{\gamma}_0)$.

$$P_{out} = P\left[\bar{\gamma} < \bar{\gamma}_o\right] \quad (4)$$

In this paper, the outage probability is calculated as the percentage of users for which the average DL SINR $(\bar{\gamma})$ is less than the required SINR to support the minimum modulation and coding scheme (MCS) (MCS0 corresponds to QPSK modulation scheme with $1/8$ code rate) $(\bar{\gamma}_0)$. In this simulation, the minimum SINR is set to $\bar{\gamma}_0 = -10\,dB$ according on [26, 27, 32].

IV. Simulation Results and Discussions

Fig. 2 illustrates the total number of handover performed as a function of the UE speed for HetNet scenario 1 and macro only scenario 2. As can be seen from Fig. 2 the total number of handovers performed in HetNet scenario 1 is higher than the total number of handovers in macro only scenario 2 at the considered different UE speeds. However, as the UE speed increases, the total number of handovers for both scenarios is increased. This is due to the fact that as UE speed increases, the UEs cross the handover regions (the cells' overlapping area) more frequently and hence the number of handover is increased. At UE speed of 120 km/hr, the total number of handover is increased by 147.5% in scenario 1 compared to scenario 2.

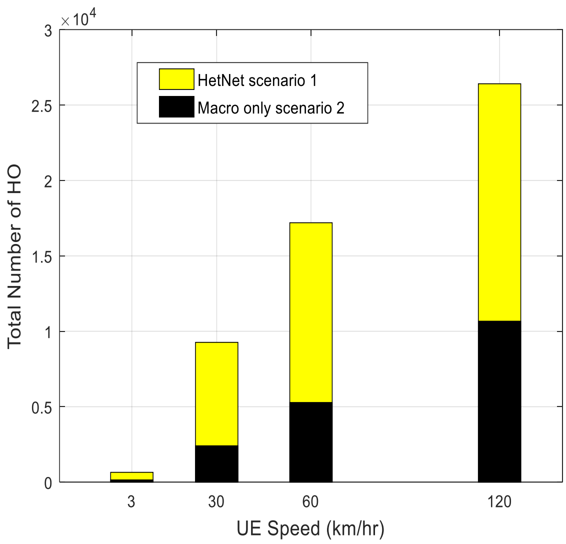

Fig. 2. Total number of handovers at different UE speeds

Fig. 3. depicts the percentages of the number of HO from macro BS to macro BS, the number of macro BS to RN HO, the number of RN to macro BS HO and the number of RN to RN HO from the total number of handovers performed in HetNet scenario 1 at different UE speeds. As can be seen for Fig. 3 that the HO between RNs has the highest percentages at different UE speeds compared to other types of HO. However, the HOs from BS to RN and from RN to BS have comparable percentages while the HO from BS to BS has the lowest percentages at the considered UE speeds. For instance, at UE speed of 3 km/hr the percentages of BS to BS HO, BS to RN HO, RN to BS HO and RN to RN HO are 5.701%, 25.42%, 32.97% and 35.9%, respectively. On the other hand, at UE speed of 120 km/hr, the percentages of BS to BS HO, BS to RN HO, RN to BS HO and RN to RN HO are 3.389%, 28.68%, 28.94% and 39%, respectively.

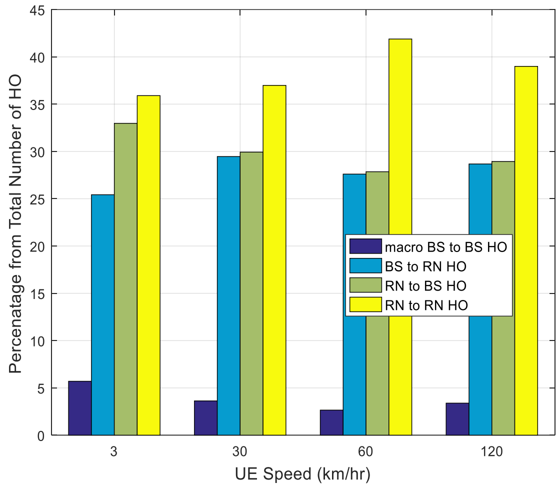

Fig. 4. Percentage of different types of HO for HetNet scenario 1 at different UE speeds

Fig. 4 illustrates the outage probability for both HetNet scenario 1 & macro only scenario 2 as a function of the UE speed. It is clear from Fig. 4 that HetNet scenario 1 with 12 RNs per cell has lower outage probability compared to macro only scenario 2 without RNs. However, as UE speed increases, the outage probability is increased for both scenarios. In fact, at UE speed of 3 km/hr, the outage probability of HetNet scenario 1 is 0.16% whereas it is 0.26% for macro only scenario 2. On the other hand, at UE speed of 120 km/hr, the outage probabilities for scenario 1 and 2 are 3.6% and 6.7%, respectively.

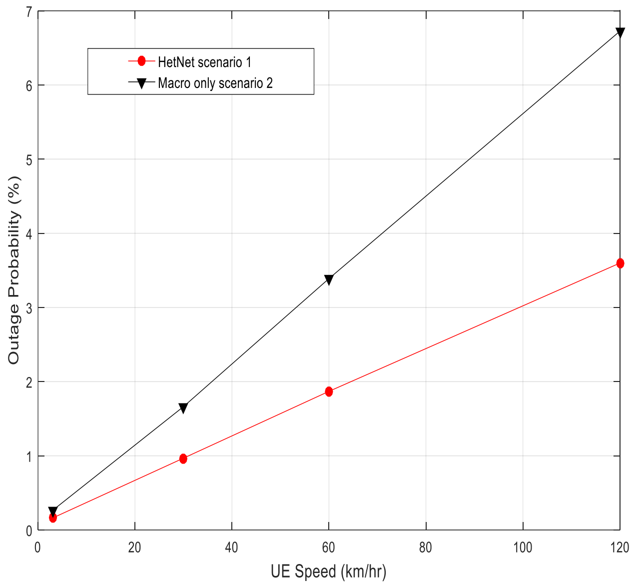

Fig. 3 Outage probability at different UE speeds

Fig. 5. depicts the total number of handover performed for scenario 1 and scenario 2 as a function of the value of A3 offset (hysteresis margin). The considered UE speed is 30 km/hr. As can be seen from Fig. 5, the total number of handover performed in HetNet scenario 1 is higher than that in macro only scenario 2 at the considered A3 offset values. Furthermore, as the value of A3 offset increases, the total number of handovers for both scenarios are decreased. This is due to the fact that at lower values of A3 offset, the handover criteria (A3 event) is easily satisfied which increases the number of performed handovers. On the other hand, as A3 offset is increased, the handover criteria is hardly satisfied which results in decreasing the number of performed handovers. In fact, when the A3 offset value is increased from 1 dB to 8 dB, the total number of handover in HetNet scenario 1 is decreased by 39.95% whereas the total number of handover in macro only scenario 2 is decreased by 45.38%.

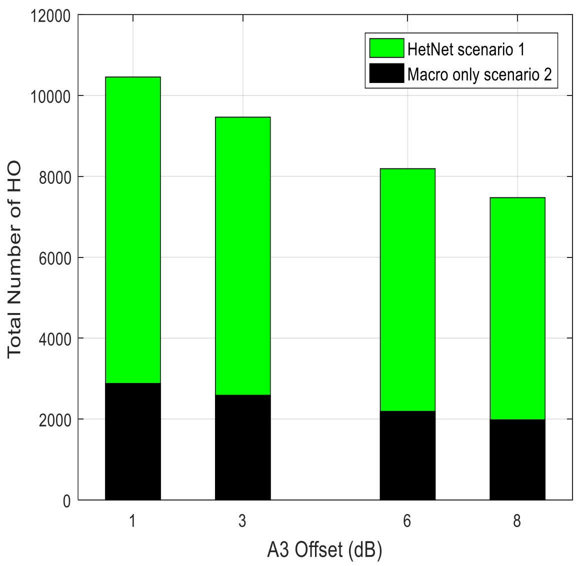

Fig. 5. Total number of handovers at different values of A3 offset

Fig. 6 depicts the percentages of the number of HO from macro BS to macro BS, the number of macro BS to RN HO, the number of RN to macro BS HO and the number of RN to RN HO from the total number of handovers performed in HetNet scenario 1 at different A3 offset values. As can be seen from Fig. 6 that at the considered values of A3 offset, the HO between RNs has the highest percentages compared to other types of HO. However, the HOs from BS to RN and from RN to BS have comparable percentages whereas the HO from BS to BS has the lowest percentages at the considered A3 offset values. For instance, at A3 offset value of 1 dB, the percentage of BS to BS HO, BS to RN HO, RN to BS HO and RN to RN HO are 4.849%, 27.5%, 28.06% and 39.59%, respectively. On the other hand, at A3 offset value of 8 dB, the percentage of BS to BS HO, BS to RN HO, RN to BS HO and RN to RN HO are 1.659%, 26.2%, 27% and 45.14%, respectively.

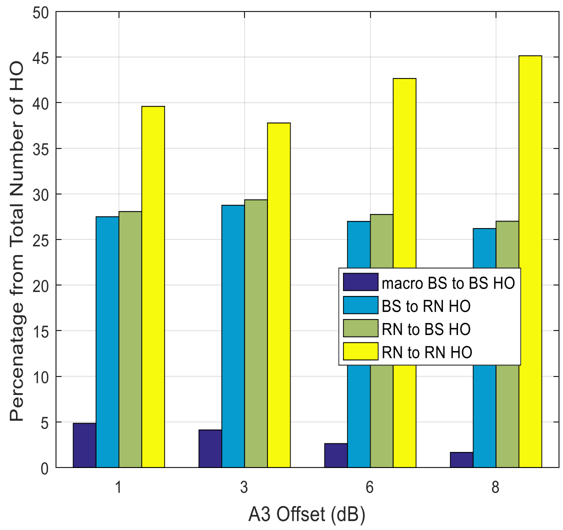

Fig. 6. Percentage of different types of HO for HetNet scenario 1 at different A3 offset values

Fig. 7 illustrates the outage probability for both scenarios at different values of A3 offset parameter. It is clear from Fig. 7 that the HetNet scenario 1 has lower outage probability compared to macro only scenario 2. Furthermore, the outage probabilities for both scenarios are increased when the value of A3 offset is increased. This is due to the fact that at lower values of A3 offset, the handover criteria (A3 event) is easily satisfied which increases the number of performed handovers and hence decreases the outage probability of the cell edge users. On the other hand, as the value of A3 is increased, the handover criteria is hardly satisfied which results in decreasing the number of performed handovers and hence increasing the outage probability of the cell edge users. Furthermore, the outage probability in macro only scenario 2 is more affected by increasing the value of the A3 offset compared to HetNet scenario 1. In fact, when A3 offset is increased from 1 dB to 8 dB, the outage probability is increased from 1.147% to 1.522% in scenario 1 whereas the outage probability is increased from 1.623% to 3.91% in scenario 2.

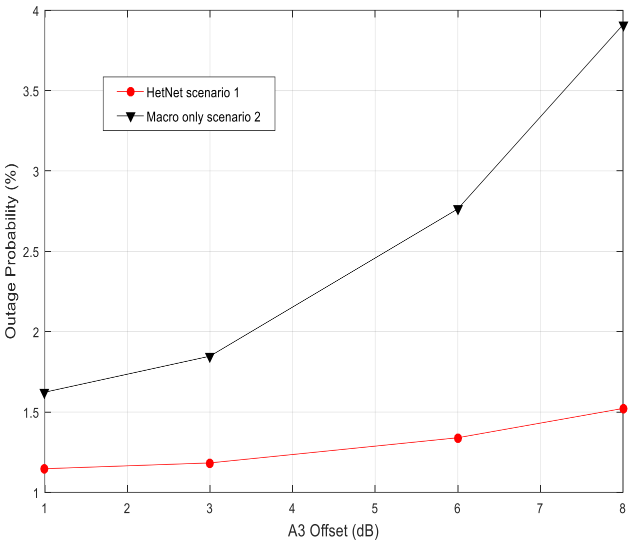

Fig. 7. Outage probability at different values of A3 offse

Fig. 8 shows the total number of HO for both scenario 1 and scenario 2 at different values of TTT parameter. However, the considered values of TTT are 1 (40ms), 4 (160ms), 8 (320ms) and 12 (480ms). As can be seen from Fig. 8, the total number of handover performed in scenario 1 is higher than the total number of handovers in scenario 2 at the considered different values of TTT parameter. Furthermore, as the value of TTT increases, the difference between the total number of handovers in scenario 1 and scenario 2 is decreased. In fact, at TTT value of 1 (40ms), the total number of HO in HetNet scenario 1 is increased by 284.9% compared to that in macro only scenario 2. However, at TTT value of 12 (480ms), the total number of handover in scenario 1 is increased by 70.3% compared to that in scenario 2.

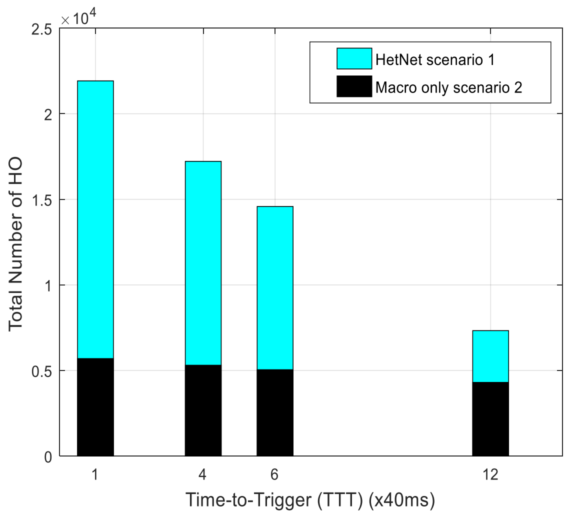

Fig. 8. Total number of handovers at different values of TTT parameter

Fig. 9 illustrates the percentages of the number of HO from macro BS to macro BS, the number of macro BS to RN HO, the number of RN to macro BS HO and the number of RN to RN HO from the total number of handovers performed in HetNet scenario 1 at different values of TTT parameter. As can be seen for Fig. 9 that the HO between RNs has the highest percentages at different TTT values compared to the other types of HO. However, the HOs from BS to RN and from RN to BS have comparable percentages. On the other hand, the HO from BS to BS has the lowest percentages at the considered TTT values. For instance, at TTT value of 4, the percentages of BS to BS HO, BS to RN HO, RN to BS HO and RN to RN HO are 2.614%, 27.29%, 27.69% and 42.4%, respectively. On the other hand, at TTT value of 12, the percentages of BS to BS HO, BS to RN HO, RN to BS HO and RN to RN HO are 11.79%, 28.13%, 29.74% and 30.35%, respectively.

Fig. 10 illustrates the outage probability for both scenario 1 and scenario 2 at different values of TTT parameter. It is obvious from Fig. 10 that the HetNet scenario 1 has lower outage probability compared to macro only scenario 2. Moreover, the outage probabilities for both scenarios are increased as the value of TTT is increased. In fact, when the value of TTT is increased from 1 (40ms) to 12 (480ms), the outage probability of scenario 1 is increased from 0.02% to 7% whereas the outage probability is increased from 0.2% to 13.71% in scenario 2. This is due to the fact that as the value of TTT is increased, the handover procedure takes longer time to be performed which results in decreasing the number of performed handovers and hence increasing the outage probability of the cell edge users.

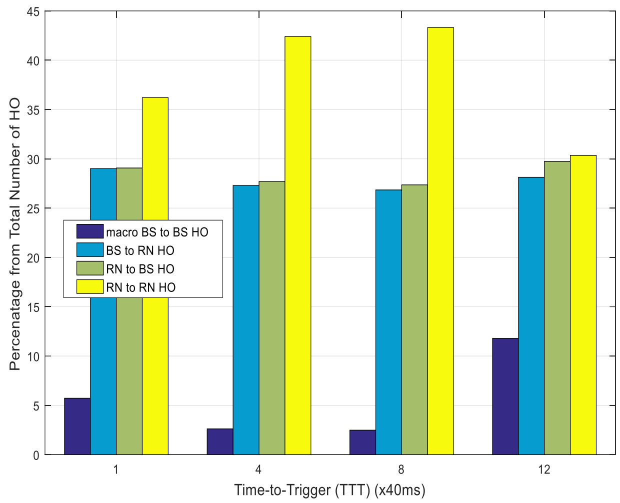

Fig. 9. Percentage of different types of HO for HetNet scenario 1 at different TTT values

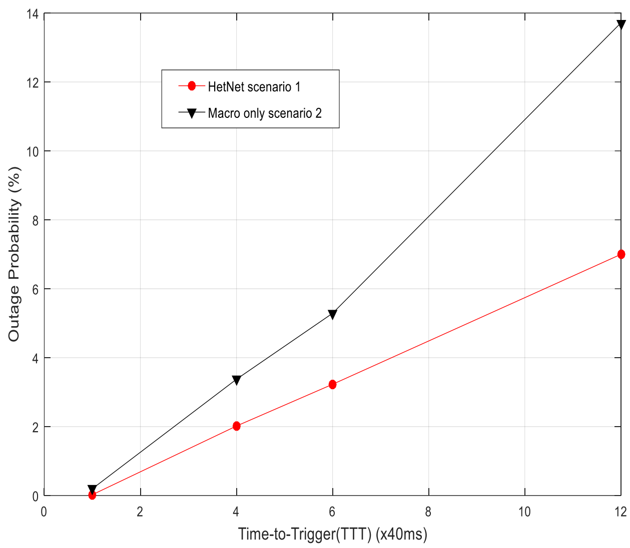

Fig. 10. Outage probability at different values of TTT parameter

V. CONCLUSION

In this paper, the performance of HHO in 5G HetNet is investigated. In fact, the effects of UE speed, A3 offset parameter and TTT parameters on the total number of performed HO and on the outage probability are evaluated. Two scenarios are considered and compared; namely HetNet scenario 1 and macro only scenario 2. Simulations results show that HetNet scenario 1 has lower outage probability compared to macro only scenario 2 at different UE speeds, different values of A3 offset and TTT parameters. However, this improvement comes at the cost of increasing the total number of HO performed in HetNet scenario 1 compared to macro only scenario 2. The cost of increased HO rates is higher signaling overheads caused by HO procedure. In addition, as the UE speed increases, the total number of HO and the outage probability are increased for both scenarios. The percentage of the number of RN to RN HO from the total number of HO performed are the highest while the percentage of the number of macro BS to macro BS HO are the lowest. Simulation results also show that as the value of A3 offset increases or as the value of TTT parameter increases, the total number of HO is decreased while the outage probability is increased for both scenarios.

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