Analysis and Performance Evaluation of Conditional Handover in 5G Beamformed Systems

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Abstract—Higher frequencies that are introduced in 5G networks cause rapid signal degradation and challenge user mobility. In recent studies, a conditional handover procedure has been adopted for 5G networks to enhance user mobility robustness. In this paper, mobility performance of the conditional handover is analyzed for 5G mm-Wave systems with beamforming. In addition, a random access procedure is proposed that increases the chance of contention-free random access during handover, which reduces signaling and interruption time. Results show that the overall failure performance improves with conditional handover scheme and the contention-free random access rate increases for the proposed random access scheme.

Index Terms—5G, mm-Wave, mobility, RACH, CHO.

I. INTRODUCTION

In cellular networks, demand for user data throughput will continue to increase dramatically [1]. The range of carrier frequency has been further expanded to mm-Wave frequencies in fifth generation (5G) cellular networks to meet the increasing demand of user data throughput. In addition, the number of base stations (BSs) with smaller coverage area is increased which improves frequency reuse and the total network capacity. Besides, higher carrier frequencies enable the deployment of many small-sized antennas that are used for directional signal transmission, resulting in beamforming gain.

Operating at higher carrier frequencies challenges user mobility due to steep and high diffraction loss which can lead to rapid signal degradation caused by obstacles [2]. Moreover, dense BS deployment increases the number of handovers which can cause frequent interruption of the user equipment (UE) connection, signaling overhead and latency [2].

Baseline handover (BHO) procedure that is used in Long Term Evolution (LTE) is reused for 5G networks in the 3rd Generation Partnership Project (3GPP) release 15 [3], [4]. The time instant for triggering the handover in BHO is critical. This is because the signal of the serving cell should be good enough to receive the handover command and the signal of the target cell should be sufficient for access. This is more pronounced in mm-Wave frequencies due to the rapid signal degradations and dense BS deployment.

Conditional handover (CHO) is introduced in [5] for New Radio (NR) 3GPP release 16 to increase the mobility robustness of the BHO. In CHO, the coupling between handover preparation and execution is resolved by introducing a conditional procedure, where handover is prepared early by the serving cell and access to the target cell is performed later when its radio link is sufficient. Furthermore, a contention-free random access (CFRA) procedure is defined in [4] where the target cell of the handover can allocate CFRA resources for the UE during the handover. Using CFRA instead of contention-based random access (CBRA) resources helps to avoid collision in random access, and consequently, mobility interruption and signaling overhead.

In this paper, a resource efficient random access procedure is proposed such that the utilization of CFRA resources is increased, especially for CHO. Moreover, the mobility performance of CHO is analyzed for current 3GPP and proposed random procedures, and compared against BHO.

The paper is organized as follows. The UE measurements that are used for handover are presented along with BHO and CHO in Section II. The random access procedure that is defined in 3GPP is revisited and our proposed random access procedure is presented in Section III. The simulation scenario is explained in Section IV. Simulation results are presented in Section V to show the performance of CHO and BHO in 5G mm-Wave networks for different random access procedures. The paper is concluded in Section VI.

II. UE MEASUREMENTS AND HANDOVER MODELS

In mobile networks, it is necessary to hand off the link of a UE between cells to sustain the user connection with the network. This handover is performed through UE received signal power measurements for serving and neighboring cells and by following a predefined handover procedure. In this section, baseline handover and conditional handover procedures are reviewed along with the relevant UE measurements for mobility.

A. UE Measurements in New Radio Beamforming System

A UE $u$ in the network monitors the Reference Signal Received Power (RSRP) $P_{RSRP}(n)$ in dBM at discrete time instant $n$ for beams $\forall b \in B$ of cell $\forall c \in C$. The separation between the instants is given by $\Delta t$ ms. The physical raw RSRP measurements are inadequate for handover decisions since those measurements fluctuate over time due to fast fading and measurement errors which would lead to unstable handover decisions. To mitigate those channel impairments, a moving average Layer-1 (L1) filter and an infinite impulse response (IIR) Layer-3 (L3) filter are applied by the UE to RSRP measurements sequentially. The implementation of L1 filtering is not specified in 3GPP standardization and it is UE specific,
i.e., it can be performed either in linear or dB domain. The L1 filter output can be expressed as

\[ P_{c,b}^{L1}(m) = \frac{1}{N_{L1}} \sum_{k=0}^{N_{L1}-1} P_{c,b}^{\text{RSRP}}(m-k), \quad m = n\omega \] (1)

where \( \omega \in \mathbb{N} \) is normalized by time step duration \( \Delta t \), and \( N_{L1} \) is the number of samples that are averaged in each L1 measurement period. For cell quality derivation of cell \( c \), set \( B_{str,c} \) of beams having measurements above threshold \( P_{\text{th}} \) is determined as

\[ B_{str,c} = \{ b | P_{c,b}^{L1}(m) > P_{\text{th}} \}. \] (2)

The subset \( B_{str,c}^{L1}(m) \) consists of \( N_{str} \) beams of \( B_{str,c} \) with the strongest \( P_{c,b}^{L1}(m) \) and L1 RSRP measurement of those beams are averaged to derive L1 cell quality of cell \( c \) as

\[ P_{c}^{L1}(m) = \frac{1}{|B_{str,c}^{L1}(m)|} \sum_{b \in B_{str,c}^{L1}(m)} P_{c,b}^{L1}(m). \] (3)

Cardinality of the set is denoted by \( | \cdot | \) and the set \( B_{str,c} \) is adopted as \( B_{str,c}^{L1}(m) \) in case \( |B_{str,c}(m)| < N_{str} \). If \( B_{str,c}(m) \) is empty, \( P_{c}^{L1}(m) \) is equal to highest \( P_{c,b}^{L1}(m) \).

L1 cell quality is further smoothed by L3 filtering and L3 cell quality output is derived by the UE as

\[ P_{c}^{L3}(m) = \alpha P_{c}^{L1}(m) + (1 - \alpha) P_{c}^{L3}(m - \omega), \] (4)

where \( \alpha = \left( \frac{\gamma}{2} \right)^{\frac{k}{2}} \) is the forgetting factor that controls the impact of older measurements \( P_{c}^{L3}(m - \omega) \) and \( k \) is the filter coefficient of the IIR filter [4].

Similarly, the L3 beam measurement \( P_{c,b}^{L3}(m) \) of each beam is evaluated by L3 filtering of L1 RSRP beam measurements as

\[ P_{c,b}^{L3}(m) = \alpha' P_{c,b}^{L1}(m) + (1 - \alpha') P_{c,b}^{L3}(m - \omega), \] (5)

where \( \alpha' \) can be configured separately from \( \alpha \).

L1 RSRP beam measurements \( P_{c,b}^{L1}(m) \), L3 cell quality measurements \( P_{c}^{L3}(m) \), and L3 beam measurements \( P_{c,b}^{L3}(m) \) of all cells in \( C \), \( \forall b \) that are used during the handover and the random access channel (RACH) procedure are illustrated in Figure [1]

**B. Baseline Handover**

L3 cell quality measurements \( P_{c}^{L3}(m) \) are used to assess the quality of the radio links between the UE and the serving and neighboring cells. To this end, UE reports the L3 cell quality measurements \( P_{c}^{L3}(m) \) and beam measurements \( P_{c,b}^{L3}(m) \) to its serving cell \( c_0 \) if the following condition (A3)

\[ P_{c_0}^{L3}(m) + \sigma_{c_0,c}^\text{add} < P_{c_0}^{L3}(m) \quad \text{for} \quad m_0 - T_\text{TTA} < t < m_0, \] (6)

expires at time instant \( m = m_0 \) for any cell \( c \neq c_0 \). The cell-pair specific offset \( \sigma_{c_0,c} \) can be configured differently by serving cell \( c_0 \) for each neighboring cell \( c \) and time-to-trigger \( T_\text{TTA} \) is the observation period of condition (6) before triggering measurement report.

After receiving L3 cell quality measurements, the serving cell sends a handover request to a target cell \( c \), e.g., typically the strongest cell, along with the L3 beam measurements \( P_{c,b}^{L3}(m) \) of target cell \( c \). Then, the target cell reserves CFRA resources (preambles) for beams \( b \in B_{\text{prevc}} \) with the highest power based on reported \( P_{c,b}^{L3}(m) \). The target cell prepares the handover command including reserved CFRA resources and sends it to the serving cell as part of the preparation acknowledgment. After that, the serving cell sends the handover command to the UE. The command comprises the target cell configuration and CFRA preambles that are reserved by the target cell \( c \). After receiving the handover command, the UE detaches from the serving cell and initiates the random access towards the target cell.

In this handover scheme, the radio link between UE and serving cell should be good enough to send the measurement report in the uplink and receive the handover command in the downlink. This is a necessary but not sufficient condition for completing the handover successfully. In addition, the radio link quality between the UE and the target cell should also be sufficient so that the signaling between UE and the target cell is sustained during the RACH procedure. In a typical system level mobility simulation, the link quality of the UE is assessed by Signal-to-Interference-Noise Ratio (SINR). Herein, the link quality conditions for successful handover between serving cell \( c_0 \) and target cell \( c \) are expressed as

\[ \gamma_{c_0,b}(m_0) > \gamma_{\text{out}}, \] (7a)

\[ \gamma_{c_0,b}(m_0 + T_p) > \gamma_{\text{out}}, \] (7b)

\[ \gamma_{c,b}(m_0 + T_p) > \gamma_{\text{out}}, \] (7c)

where \( \gamma_{c,b}(m) \) and \( \gamma_{c_0,b}(m) \) are the SINR of the links between UE and the beam \( b \) of target cell \( c \) and serving cell \( c_0 \), at time \( m \), respectively. \( m_0 \) is the time instant the measurement report is sent and \( T_p \) is the latency of handover preparation between serving and target cell. \( \gamma_{\text{out}} \) is the SINR threshold that is required for maintaining radio communication between UE and network (e.g., \(-8 \text{ dB} \)).

As shown in (7a), (7b) and (7c), the time instant \( m_0 \) for triggering the measurement report is critical for the success of the handover. When moving towards the coverage area of the target cell, delaying \( m_0 \) helps the conditions in (7b) and (7c) to be fulfilled for serving cell \( c_0 \) and target cell \( c \), respectively, at the expense of having weaker \( \gamma_{c_0,b}(m_0) \) for serving cell \( c_0 \) to risk the condition of (7a), and vice-versa.

**C. Conditional Handover**

In conditional handover, the handover preparation and execution phases are de-coupled, which helps to receive the handover command safely from the serving cell and to access the target cell later when its radio link is sufficient.

Similar to A3 condition (6), an Add condition is defined as,

\[ P_{c_0}^{L3}(m) + \sigma_{c_0,c}^\text{add} < P_{c_0}^{L3}(m) \quad \text{for} \quad m_0 - T_\text{TTA} < t < m_0, \] (8)

where \( \sigma_{c_0,c}^\text{add} \) is defined as add offset. The UE sends the measurement report to serving cell \( c_0 \) at \( m = m_0 \) if the Add condition is fulfilled for \( T_\text{TTA} \) seconds. Then, the serving cell \( c_0 \) sends the handover request to the target cell \( c \) for the
III. RACH PROCEDURE IN NEW RADIO MULTI-BEAM SYSTEM

In this section, the basics of random access are reviewed. Then, the 3GPP RACH procedure of NR is described and our proposed RACH procedure is introduced.

A. Contention-free and Contention-based Random Access

Random access is the first signaling performed by a UE for establishing the synchronization with a cell. The UE initiates the random access by sending a RACH preamble to the target cell. However, it is possible that multiple UEs use the same preamble during the random access towards the same reception beam of a target cell. In this case, RACH collision occurs which is then resolved by additional signaling and delay for completing random access. This type of random access where a UE selects one preamble out of set that is common for all UEs is called CBRA.

In handover, the collision risk can be avoided by assigning dedicated preambles to each UE to be used towards a prepared beam \( b \in B_{\text{prep},c} \) of the target cell \( c \). The network identifies the UE signal without further signaling and delay if the UE accesses the prepared beam using the dedicated preamble. This kind of random access is called CFRA.

B. Access Beam and Preamble Selection

During handover, accessing the target cell by using a dedicated CFRA preamble is preferable due to lower latency and signaling requirements than CBRA. Although a set of beams \( b \in B_{\text{prep},c} \) of the target cell \( c \) with the strongest L3 beam quality measurements \( P_{L3}^{b,c} \) can be prepared with CFRA resources, measurements of those beams may vary between the preparation time instant \( m = m_0 \) and access time \( m = m_1 \) due to the de-coupling between the phases. Variation of beam measurements is more significant in conditional handover compared to baseline handover. This is because, in baseline handover, the elapsed time between the preparation and access phases is given by \( T_p \) in (7c). However, in conditional handover, this time is longer than \( T_p \) since the UE waits \( T_o \) until the Execution condition is fulfilled after receiving the handover command. In CHO, \( T_o \) can be much larger than \( T_p \).

Due to the temporal variation of beam measurements, the access beam is selected based on measurements at time instant \( m = m_1 \) of CHO execution. This is illustrated in Figure 2. Herein, the UE selects the access beam \( b_0 \) from set of prepared beams \( B_{\text{prep},c} \) as follows

\[
b_0 = \arg\max_b P_{L3}^{b,c}(m_1), \quad P_{L3}^{b_0,c}(m_1) > \xi_{\text{access}}, \quad b_0 \in B_{\text{prep},c},
\]

where \( \xi_{\text{access}} \) is the threshold that L1 RSRP beam measurements shall exceed to consider prepared beams for access. Ultimately, the UE accesses the prepared beam \( b_0 \) that satisfies

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**Fig. 1.** Diagram of L1 and L3 UE measurements which are derived from Reference Signal Received Power (RSRP) for beams of cell \( c \).
Select the beam with strongest measurement.

**Figure 2.** Herein, the UE uses CFRA resources if the selected issue, an enhancement is proposed as shown in green color in associated with the selected strongest beam. To tackle this UE may make CBRA although there are CFRA resources above the threshold $\gamma$. None of the L1 RSRP measurement of prepared beams is eventually lead to less signaling and latency during the RACH procedure.

In 3GPP standardization, CBRA preambles are used if none of the L1 RSRP measurement of prepared beams is above the threshold $\xi_{access}$. This has the disadvantage that the UE may make CBRA although there are CFRA resources associated with the selected strongest beam. To tackle this issue, an enhancement is proposed as shown in green color in Figure 2. Herein, the UE uses CFRA resources if the selected beam is prepared beam $b_0$ with the strongest L1 RSRP beam measurement is selected as

$$b_0 = \arg \max_b P_{c,b}^{\text{L1}}(m_1). \tag{11}$$

In 3GPP standardization, CBRA preambles are used if none of the L1 RSRP measurement of prepared beams is above the threshold $\gamma_{access}$. This has the disadvantage that the UE may make CBRA although there are CFRA resources associated with the selected strongest beam. To tackle this issue, an enhancement is proposed as shown in green color in Figure 2. Herein, the UE uses CFRA resources if the selected beam is prepared beam $b_0$ with the strongest L1 RSRP beam measurement $P_{c,b_0}^{\text{L1}}$ is below the threshold $\xi_{access}$. This will eventually lead to less signaling and latency during the RACH procedure.

**IV. SIMULATION SCENARIO AND PARAMETERS**

In this section, the investigated scenario, mobility and propagation parameters are described. These will be used to compare the different mobility performance indicators of BHO and CHO for 3GPP and proposed RACH procedures and for various random access beam thresholds $\xi_{access}$.

In this study, the Madrid Grid layout that is described in the METIS 2 project [6] is used. The layout is given in Figure 3 and consists of buildings (grey), streets (black), open square (blue) and pedestrian area (green). There are 33 3-sector macro cells which are located on the roof tops of the buildings. The users are distributed as follows: 200 users are moving in the streets with 30 km/h in both directions. Besides, 40 pedestrian users are walking in the open square and 80 users are walking in the pedestrian area with 3 km/h.

The scenario parameters are specified in Table I along with the configuration of the transmit antenna panels. Beams $b \in \{1, 8\}$ have smaller beamwidth and higher beamforming gain to cover far regions of the cell coverage area where beams $b \in \{9, 12\}$ with larger beamwidth and relatively smaller beamforming gain are defined to serve regions near to the base stations. The SINR $\gamma_{c,b}(m)$ of a link between UE and beam $b$ of cell $c$ is evaluated by the approximation given in [7] for the strict resource fair scheduler.

**Handover Failure Model:** Handover failure (HOF) is a metric that is used to evaluate the mobility performance. For both 3GPP and proposed RACH procedures, a UE decides to use either CBRA or CFRA preamble as shown in Figure 2 and attempts to access the selected beam $b_0$ of target cell $c$ with the selected preamble. For successful random access, it is required that the SINR $\gamma_{c,b_0}(m)$ of the target cell remains above the threshold $\gamma_{out}$, during RACH procedure. A handover failure timer $T_{304} = 500$ ms is started when the UE starts the random access and sends the RACH preamble. The RACH procedure in Figure 2 is repeated until a successful RACH attempt is achieved or $T_{304}$ expires. In the handover failure model, a UE may succeed to access the target cell only if the $\gamma_{c,b_0}(m)$ exceeds the threshold $\gamma_{out}$. HOF is declared if $T_{304}$ expires and the UE fails to access the target cell, i.e., $\gamma_{c,b} < \gamma_{out}$. Once HOF is declared, the UE performs connection re-establishment which requires additional signaling and causes latency [4].

**Radio Link Failure Model:** Radio link failure (RLF) is another key metric that is relevant for mobility performance. An RLF timer $T_{310} = 600$ ms is started when SINR $\gamma_{c,b}(m)$ of serving cell $c_0$ falls below $\gamma_{out}$ and RLF is declared if $T_{310}$ expires. During the timer, the UE may recover before detecting RLF if SINR $\gamma_{c,b}$ exceeds the second threshold $\gamma_{in}$ which is higher than $\gamma_{out}$. A detailed explanation of the procedure is given in [4].
In this section, the proposed RACH procedure is compared against that of 3GPP for BHO and CHO. The key performance indicators (KPIs) used for comparison are explained below.

A. KPIs

1) CBRA Ratio \(\left(R_{\text{CBRA}}\right)\): Total numbers of successful CBRA and CFRA procedures that are observed during a mobility simulation are denoted by \(N_{\text{CBRA}}\) and \(N_{\text{CFRA}}\), respectively. The fraction of CBRA events in a simulation is formulated as

\[
R_{\text{CBRA}}[\%] = \frac{N_{\text{CBRA}}}{N_{\text{CBRA}} + N_{\text{CFRA}}} \times 100\%.
\]  

2) \(N_{\text{HOF}}\): Total number of HOFs that are observed during a simulation.

3) \(N_{\text{RLF}}\): Total number of RLFs that are declared in the network.

Both \(N_{\text{HOF}}\) and \(N_{\text{RLF}}\) are normalized to number of UEs and simulation time as illustrated in the following section.

B. Simulation Results

The mobility performance of the 3GPP and the proposed RACH procedure is investigated for both CHO and BHO in Figure 3. To this end, the impact of different beam access thresholds \(\xi_{\text{access}}\) values and number of prepared beams \(N_B = \left| B_{\text{prep}},c \right|\) on the aforementioned mobility KPIs of Section V.A are analyzed. Figure 4 and Figure 5 show the number \(N_{\text{HOF}}\) of handover failures per UE-minutes (UE-min) with solid line on the left axis and CBRA ratio \(R_{\text{CBRA}}\) with dashed line on the right axis as a function of \(\xi_{\text{access}}\) (in dB) for CHO and BHO, respectively. The results are shown for both proposed and 3GPP RACH procedures as well as for different number of prepared beams \(N_B = 1\) and \(N_B = 4\).

CHO Analysis: Figure 4 shows that for \(\xi_{\text{access}} = -\infty\) the UE uses only CFRA preambles \((R_{\text{CBRA}} = 0)\) for both proposed and 3GPP RACH procedures since the UE can always select a prepared beam from set of \(B_{\text{prep}},c\) of target cell \(c\). On the other hand, \(\xi_{\text{access}} = \infty\) leads to worst HOF performance because the received signal power of the prepared beam changes over time and the prepared beam does not always remain a good candidate during the time between handover preparation and execution phases. Ultimately, the SINR \(\gamma_{c,b_0}\) of the accessed beam \(b_0\) falls below \(\gamma_{\text{out}}\) which leads to HOF. This is more visible for \(N_B = 1\) since the UE does not have any other options for prepared beams. Increasing \(N_B\) from 1 to 4 reduces the access failure \(N_{\text{HOF}}\) to one third of its value since it increases the chance of selecting the strongest beam.

![Fig. 4. The number of HOFs and ratio \(R_{\text{CBRA}}\) are shown for CHO as a function of beam access threshold \(\xi_{\text{access}}\) with RACH procedure and number \(N_B\) of beams as parameters.](image-url)
selecting one of the prepared beams. As a consequence, beams with higher \( P^\text{L1}_{c,b}(m) \) are selected to be accessed which yields higher \( \gamma_{c,b_0} \) and less HOFs. On the other hand, for higher \( \xi_{\text{access}} \), UE tends to select prepared beams less frequently which results in use of CBRA preambles for random access. However, it is observed that the ratio of CBRA is much smaller for the proposed RACH procedure for higher \( \xi_{\text{access}} \). This is because the UE still performs CFRA if none of the prepared beams have beam measurements above threshold \( \xi_{\text{access}} \).

Results in Figure 4 also show that the number of HOFs of the proposed and the 3GPP RACH procedures diverge significantly at \( \xi_{\text{access}} = \infty \) and is the same for both \( N_B = 1 \) and \( N_B = 4 \). This is because the beam of the target cell with the strongest L1 RSRP measurement is selected in both RACH procedures regardless of the set of prepared beams \( B_{\text{prep,c}} \). Hence, the selected beam \( b_0 \) of target cell \( c \) with strongest measurement \( P^\text{L1}_{c,b_0} \) leads to higher SINR \( \gamma_{c,b_0}(m) \) and in turn lower HOF. However, CBRA ratios of the proposed and the 3GPP RACH procedures diverge significantly at \( \xi_{\text{access}} = \infty \). In particular, for the 3GPP RACH procedure, the UE selects only CBRA preambles for random access for any \( N_B \) value since all prepared beams have L1 measurements that are below \( \xi_{\text{access}} \). This is not the case for the proposed RACH procedure because preamble selection still considers the prepared beams although that L1 measurement is not above \( \xi_{\text{access}} \).

Furthermore, the same HOF performance of CHO is observed for both the proposed and the 3GPP RACH procedures since the HOF depends on the selected beam and both RACH procedures do not differ with respect to beam selection procedure as shown in Figure 2.

**BHO Analysis:** Figure 5 shows that HOF is not observed at BHO for any number \( N_B \) of prepared beam and beam access threshold \( \xi_{\text{access}} \). This is because, compared to the CHO results in Figure 4, the time \( T_b \) that elapses between preparation and the phases of BHO is shorter than that of CHO \( (T_p + T_b) \) and during this time the measurements of the prepared beams do not change. Consequently, UEs performs access to a beam \( b_0 \) that yields sufficient \( \gamma_{c,b_0}(m) \) at target cell \( c \).

Figure 5 also shows that the CBRA ratio of the proposed RACH procedure slightly increases for higher \( \xi_{\text{access}} \), because the measurements of the beams do not change much between preparation and access phases which is shorter than that of the CHO case. However, the CBRA ratio of the 3GPP procedure in Figure 5 gradually increases for increasing \( \xi_{\text{access}} \) as it is observed for the CHO case in Figure 4. This is also due to the fact that the 3GPP RACH procedure does not consider the prepared beams in case the L1 measurements are below the access threshold \( \xi_{\text{access}} \).

**Failure Results:** Figure 6 shows the total number of failures \( N_{\text{HOF}} + N_{\text{RLF}} \) per UE-min as a function of the beam access threshold \( \xi_{\text{access}} \) for both CHO and BHO. As it has been shown in Figure 4 and 5 that failure rate is independent of the RACH procedure, the results in Figure 6 do not differentiate the two RACH procedures. Besides, the total number of failures for BHO is the same for both \( N_B = 1 \) and \( N_B = 4 \).

It is shown in Figure 6 that the overall failure performance of BHO is improved by the conditional execution mechanism that is introduced by CHO. Furthermore, one can also state that the failures that are observed in the mobility scenario are dominated by RLF and this is improved by CHO despite the HOF increase that is observed for CHO compared to BHO, see Figure 4 and Figure 5.

**VI. Conclusion**

In this paper, conditional handover of 3GPP release 16 is analyzed for NR beamformed systems. Baseline and conditional handover procedures have been reviewed along with L1 and L3 UE measurements that are relevant for mobility. In addition, the 3GPP random access procedure is revisited and a new random access procedure is proposed that aims to increase contention-free random access and reduce in turn signaling overhead and latency during handover. The mobility performance of conditional handover is compared against baseline
handover. Simulation results have shown that the number of fall-backs to contention based random access is reduced significantly when the proposed random access procedure is used.

Moreover, the results have revealed that the baseline handover procedure causes less handover failures than conditional handover. However, the total number of failures for conditional handover is less than that of baseline handover due to the decoupled handover preparation and execution phases, providing mobility robustness.

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