Study on Impact of Vertical Sectorization on Mobility and Existing MRO Performance

Dereje W. Kifle*, Bernhard Wegmann*, Ingo Viering‡, Anja Klein§
*Nokia Networks, Munich, Germany: {dereje.woldemedhin.ext; bernhard.wegmann @nsn.com}
‡Nomor Research GmbH, Munich, Germany: {viering@nomor.de}
§Technische Universität Darmstadt Communications Engineering Lab, Darmstadt, Germany: {a.klein@nt.tu-darmstadt.de}

***Abstract*—Mobility robustness optimization (MRO) is one of the Self Organizing Network (SON) features that automatically adjusts network mobility configurations by detecting problems and correcting handover (HO) parameters. The existing MRO operation is based on stationary network deployment assumption where handover error statistics are continuously monitored between cell-pair borders as long as the cells shape and neighbor relationships are maintained. In the dynamic deployment case, where cell deployment layout is changing by following the nature of the traffic distribution, existing neighbor relationships might not be maintained and new neighbors could appear in the network. In such cases, MRO instances and counters used before deployment change might not be valid any longer for the new network layout. In this paper work, we have studied the impact of deployment and network layout change introduced by Vertical Sectorization (VS), a typical Active Antenna Systems (AAS) feature, on the performance of MRO. A crucial aspect here is the treatment of MRO statistics while introducing a change in the network deployment layout. The study gives information if there is a need to enhance the existing MRO concepts by introducing inter-node coordination during execution of a deployment change in the network.**

***Index Terms*—MRO, SON, AAS, VS, HO**

I. Introduction

Handover procedure maintains a seamless connection of mobile devices while they are moving across a network or roaming within different radio access technology (RAT) types' coverage as per the availability of the best serving sector as well as their service requirement configuration. The objective of MRO is to improve the handover performance of a network by adjusting handover parameter settings with respect to handover boundaries in an automated and self organized manner and, therefore, finally enhance the end-user experience. This is done by monitoring cell-pair, specifically, the handover events as well as related failures and unnecessary handovers [1]. In order to rely on statistics, the existing MRO operation assumes a fixed and stationary network deployment layout where neighbor relationships as well as cell shape are not changed for longer period of time as depicted in Figure 1 (a).

In an AAS-enabled network, however, dynamic deployment changes are possible where further sectorization can be done via cell-splitting or sector layout restore/reshape can be also done with cell-merging process. Figure 1(b) illustrates the case of vertical sectorization [2] where an inner sector is activated

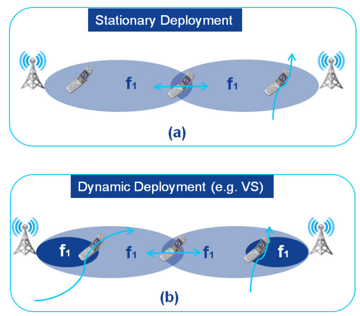

Fig. 1. Vertical Sectorization

resulting in inner/outer sector coverage over the conventional sector layout. This leads to an introduction of new sector boundaries and a moving user could traverse across additional handover boundaries with non-optimized handover threshold value if the neighbor cell has not been informed about the cell change. In such cases, the mobility event statistics collected by MRO might not be valid any longer and would screw up the exiting statistics. MROs statistical mobility and failure event analysis is per cell-pair. Introducing a new cell with new cell border or changing cell shape requires new statistics due to modified propagation and, in addition, new MRO instances for new cell-pairs. As a consequence, 3GPP has been discussing on the need for further enhancement for existing MRO and has approved a work item (WI) to standardize SON enhancements for AAS-based deployments [3]. Therefore, detailed studies on the AAS-enabled deployment change are required to identify related issues towards user mobility, service continuity problems and also to evaluate the performance of MRO with respect to the new deployment layout after a change is applied.

In this work, the impact of dynamic deployment change has been studied for the vertical sectorization case where inner sector is activated/deactivated during a cell-splitting/merging procedures respectively on a fixed deployment network layout. The investigation addresses the following important aspects with respect to user mobility and MRO operation:

- Performance comparison of MRO before and after deployment change,
- Cell borders where for one of them VS has been carried out ,
- Optimal handover offset setting to be used for quick

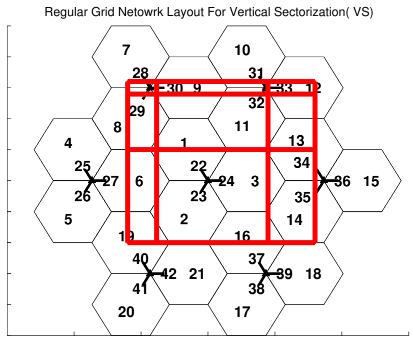

Fig. 2. Network Layout and Street Model

adaptation of handover after a deployment change,

- Optimal treatment of collected MRO event statistics and optimized parameters of the previous deployment situation.

The paper is organized as follows. The scenario description and utilized network deployment layout is presented in section II. Results with detail analysis and explanation are shown in Section III and Section IV concludes the work.

II. System Model and Deployment Scenario

AAS-based LTE deployment is assumed with 7 tri-sectored fixed sites consisting of 21 conventional sectors. A macro sector layout is considered and an Inter-Site Distance (ISD) of 1732 m is assumed, as defined by the 3[rd] Generation Partnership Project (3GPP). A wrap-around mechanism is used to properly include the inter-cell interference situations for outer sectors. For the investigation, a deployment change is introduced using the vertical sectorization (VS) case by activating a new inner sector with a higher downtilt with respect to the original sector, which is called here as an outer sector in the context of VS. This VS state is referred as VS=ON in this paper. On the other hand when the VS feature is turned-off, the inner sector is deactivated and the outer sector takes over the conventional sector layout coverage; this state is referred as VS=OFF state. The activation/deactivation processes are applied in the network simultaneously at all sites in a synchronous manner to introduce high level of sector layout change in the network. The same antenna parameters configuration are assumed for the inner and outer sector beams but with a different tilt setting values applying a 7° degree offset between them to minimize sector overlaps [2][4]. Despite the fact that both inner/outer sectors are of the same RAT type and located on the same eNB, a different shadow map with 50% correlation is assumed to take into account the change in the propagation condition at different tilt in scatter-rich urban clatter environment [5][6]. A street grid has been modeled in the network in such a way that, fast moving users cross various handover boundaries where deployment change related mobility problems can potentially occur. The streets model our civilized behavior leading to areas with high handover concentration and higher failure frequency. Two types of users are considered: fast moving street users with speed of 60 km/hr and background pedestrian users randomly traveling outside from the streets with 3 km/h. Other system parameter values and network settings utilized are presented in Table I.

TABLE I
System Parameters and Settings

System Model and Parameter Settings		
Description	Parameter	Value
Site	ISD # Site Height [m]	1732 m 7 Tri-sectored Antenna =30, UE = 1.5
Sector-Power	Inner-Sector Outer-Sector	26 dBm/PRB 26 dBm/PRB
Antenna	Gain[dBi] Φ_{3dB} Θ_{3dB} Inner-Tilt Outer-Tilt Backward Attenuation	14 70° 10° 13° 6° 25 dB
Propagation	Pathloss Shadowing Std. Penetration Loss	$128.1{+}37.6{\cdot}\log_{10}(r_{km})$ 8 dB 20 dB

User Infomarion	# UEs
	Type
	
	Speed
		1000
		Moving UEs(# Fast = 700, # Slow = 300)
		Fast = 60 km/h, Slow = 3 km/h

System Setting	RAT-Type Frequency Bandwidth Operating Mode	LTE 2 GHz 10 MHz Down-Link
Cell-ID Range	Outer-Sector Inner-Sector	1-21 22-42
MRO Settings	MRO Optimization Simulation Time-Step KPI Collection Period Ping-Pong Weight	Intra-RAT,Intra-Frequency 50 ms 90 s 0.2

III. Study Analysis for Various Scenarios

A. Connection Failures and MRO Performance for VS=OFF and VS=ON

In this section, mobility related connection failures are studied separately for VS=OFF and VS=ON deployment states. In each deployment case, a default initial handover offset called Cell Individual Offset (CIO) is used for each handover source-target cell-pair and it is set to 0 dB. Moreover, MRO operation is enabled to optimize the CIO values to reduce failures related to handover events. The details of the MRO algorithm utilized is explained in [7][8].

3GPP defined handover related failure types are employed in the MRO operation to monitor the mobility related connection failures occurring in order to adapt the CIO value at the corresponding handover boundary. Thus, total number of handover event problems referred here as Connection failure count(ConeFC) is defined as the sum of the handover events that lead to connection failure due to Radio Link Failures (RLFs) and Handover Failures (HoFs) which are handover events that are initiated but not completed. These are: Too-Late Handover (HO_{TL}), Too-Early Handover (HO_{TE}) and Handover to Wrong Cell (HO_{WC}) [1]. Ping-Pongs(PPs) which are

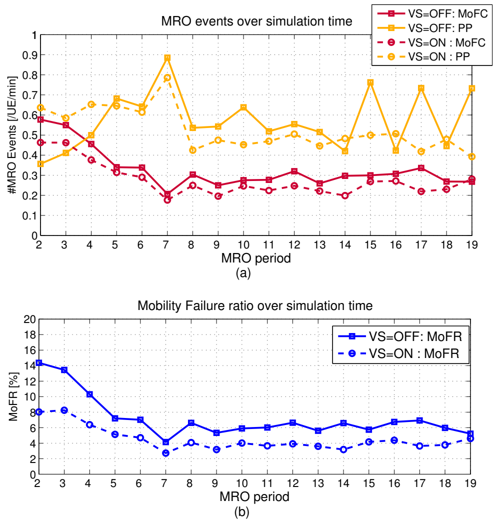

Fig. 3. Connection Failures Event Statistics

also handover-related problems that causes signaling over head in the system due to unnecessary back-and-forth of handover events are also considered here [1].

$$\begin{aligned} RLF &= HO_{TL} + HO_{TE(RLF)} + HO_{WC(RLF)} \\ HoF &= HO_{TE(HoF)} + HO_{WC(HoF)} \\ ConeFC &= RLF + HoF \end{aligned} \tag{1}$$

All MRO event statistics are collected from the complete network area in each MRO period defined in the Table I. The ConeFC is presented here as normalized to the number of total UEs in the network and the MRO counter collection period in minute. In addition to the connection failures, a mobility failure ratio (MFR) defined as the ratio of the total number of failed handover events over the failed plus successful handover events (HO_{suc}) is evaluated to show the fraction percentage of failed handover events, i.e.:

$$MFR = \frac{ConeFC}{HO_{suc} + ConeFC} \tag{2}$$

Figure 3 shows the ConeFC and MFR values for VS=OFF and VS=ON cases over simulation time. As can be seen in Figure 3(a), in both deployment cases, MRO is able to reduce the mobility failures by over 60% and stabilizes over time converging to the same level. On the other hand, in the case of VS=ON, despite the introduction of additional handover boundaries, the total number of failures over the complete network area is seen to be lower for VS=ON than VS=OFF case. In VS=ON case, new mobility failures are occurring as expected while users are crossing inner-outer or outer-inner sector borders: for example, from sector 14 to 35 and from sector 13 to 34 in Figure 2. However, some of the handover problems which have been occurring in VS=OFF case over the existing sector borders are seen to disappear during VS=ON as the newly activated inner sectors have provided a dominant service coverage over some of the problematic area where

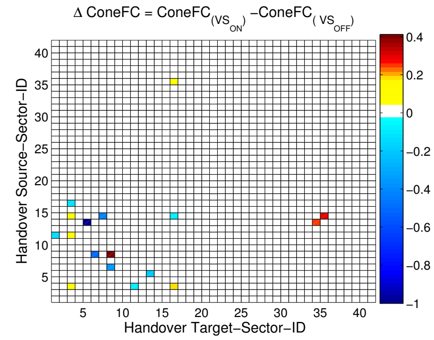

Fig. 4. Total Number of Connection Failures Over Handover Cell-Pair

many users had been experiencing an RLF. Such situation is illustrated in Figure 4 where the ConecFC difference (Δ ConeFC) is presented for each deployment scenario over the total simulation time. Accordingly, the new connection failure problems are reported for UEs traveling on the street crossing sector 13, 14, 34 and 35. Furthermore, it has been observed that more handover events have occurred in VS=ON case due to the fact that there are more additional sector boundaries, and most of the handover events are successfully completed. This is demonstrated in Figure 3(b) where the ratio MoFR is clearly lower for the VS=ON case than what can be seen in Figure 3(a). Regarding to PPs, their number have increased in the first few MRO period for the reason that our MRO algorithm reacts faster to failures than PPs, based on the ping-pong weight setting used in Table I. By adjusting the CIO in response to the dominant HO_{TL} problems, those unnecessary forth and back handovers might be caused for the corresponding cell-pair handover threshold by reducing the natural hysteresis given by the A3-offset on both sides. For VS=OFF case, after the ConeFC stabilizes,the PPs keeps oscillating and MRO couldn't react further any longer on it and this is a trade-off as both problems can not be always resolved simultaneously.

B. Storing and Fetching CIO Configuration

In the context of SON enabled dynamic deployment, configuration of network parameters should be also updated to their optimal value once the deployment layout has been changed. Depending on the frequency and dynamics of the deployment layout change, relying on SON operation to adjust network parameters all the time after deployment change could be sub-optimal solution as it might take time until it converges to the optimal values. This would lead to high service discontinuity and degraded user experience. For that matter, storing configuration parameter for a specified network deployment state and retrieving them back while restoring the deployment can be a feasible approach in such situations.

In this section of the paper, the two network deployment states are assumed to be known: VS=OFF and VS=ON, at each evolved nodeB (eNB). That is, each cell is able to immediately adapted the MRO parameter (e.g CIO values) to the deployment change. When either of the network deployment is

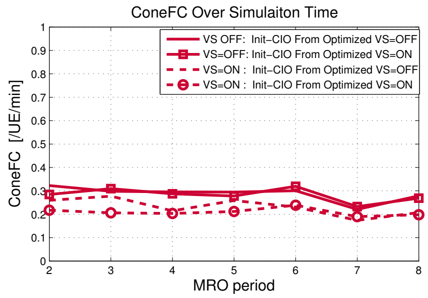

Fig. 5. Previously Optimized Initial CIO Settings

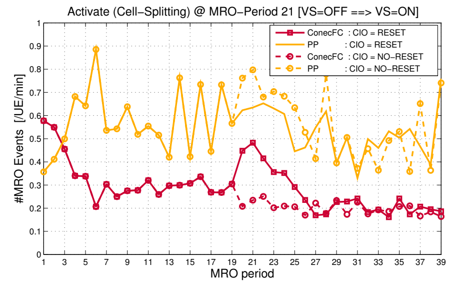

Fig. 6. Connection Failures and MRO Performance With Cell-Splitting

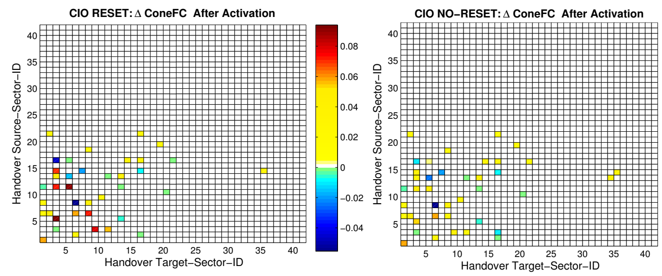

Fig. 7. Additional Connection Failures Right After Cell-Splitting

activated for the first time, the MRO algorithm runs to optimize the CIO values until it stabilizes as shown in Figure 3. The corresponding optimal CIO values can be then stored along with additional information to describe and identify the network deployment state. When a network deployment is applied (activated) again, the corresponding stored optimal CIO values can be fetched and configured as initial configuration setting. Such investigations have been carried out in this paper and observations are reported in Figure 5.

As can be seen in Figure 5, for each deployment scenario, different initial CIO (Init-CIO) is set from previously optimized CIO values, i.e. from Figure 3 (a). Accordingly, in both deployment cases, the configured optimal Init-CIO values lead to closely the same performance irrespective of to which previous deployment scenario they belong. Moreover, it can be seen that, unless additional cell layout change is introduced, fetching stored CIO configuration and reconfiguring as Init-CIO brings a stable MRO performance after the deployment change than using a default CIO configuration. This observation has been studied by initializing the MRO operation with a specified deployment layout.

In reality, however, a deployment layout change could be triggered and executed in a stable network while MRO is running. In such situation, a coordinated mechanism might be required between the MRO and the execution of the deployment change to properly hand-off users to their respective serving sectors otherwise users could experience abrupt connection failures that could result in a sudden service discontinuity. Such situations are investigated for the worst case scenario in the following section where a deployment change is applied while MRO is running by a sudden activation/deactivation of inner sectors and considering two approaches on what to do along with the deployment change. These are: resetting the respective CIO values and MRO statistics (RESET) or keeping configuration and related MRO statistics unchanged (NO-RESET) with respect to the cell pairs affected by the cell layout change.

C. Deployment Layout Change While MRO Is Running

The aim of this investigation is to study the issues related to user mobility and MRO performance by changing the deployment layout simultaneously at all sites via activating inner sectors(aka: Cell-Splitting), i.e. VS=OFF $\Longrightarrow$ VS=ON, and deactivating inner sectors (aka: Cell-Merging), i.e. VS=ON $\Longrightarrow$ VS=OFF. In this paper the two extreme approaches, i.e. CIO RESET and CIO NO-RESET, are considered to study the impact of the deployment change on the existing MRO operation.

For activation (Cell-Splitting) case, the network-wide normalized mobility event related failure counts and the corresponding performance of MRO are presented in Figure 6 for both CIO RESET and NO-RESET activation approaches. Despite the fact that, the collected MRO event statistics and respective CIO settings could be considered as invalid and sub-optimal after the corresponding deployment layout has been changed, the CIO NO-RESET approach brings no significant new mobility related issues and yields a more stable MRO performance, Figure 6. With CIO RESET approach, however, the optimized handover boundaries of the existing sector borders, i.e., between outer-outer sectors, will be affected, hence, high number of mobility failures occur during the next MRO period as can be seen in the figure, Figure 6. On the other hand, despite resetting the CIO, MRO is seen to be able to perform well and converge to a stable level over time. The PPs statistics are more or less showing not significant deviation from what has been reported in Figure 3(a), however, marginal variation is observed due to the trade offs in the MRO response towards the abrupt failures in the network. Furthermore, the connection failures right after the deployment change over handover cell-pair borders are presented normalized to the total number of users in the network in Figure 7 for both activation approach cases. Accordingly, most of the dominant failures after cell-splitting, in the case of RESET approach, occur between outer-outer sectors while relatively less failures

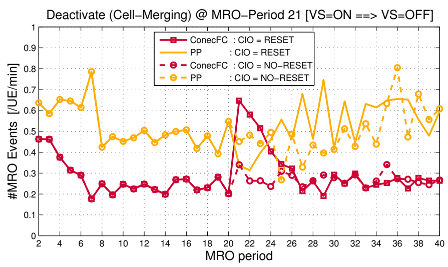

Fig. 8. Connection Failures and MRO Performance With Cell-Merging

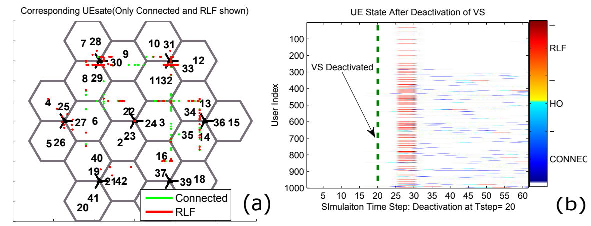

Fig. 9. User Connection State Transition after Deactivation

are reported for NO-RESET case.

For deactivation (Cell-merging) case, all inner sectors are turned off in the considered network while operating in VS=ON deployment state and MRO is actively running. In this regard, the users those have been connected to the respective inner sectors will be eventually dropped, hence, suffer from RLF. In addition to that, the CIO values optimized for the deployment layout before the Cell-merging could be not optimal any longer, as a result, additional related handover failures can occur. For this investigation scenario, RESET and NO-RESET CIO approaches have been considered like the Cell-Splitting study case mentioned above. And the normalized connection failures and the PP statistics are presented in Figure 8 while the deactivation of the inner sectors is suddenly applied at MRO period of 21. Thus, it can be seen from the figure that mobility failures have occurred in both considered deactivation approach cases for the apparent reason mentioned above, while the failure rate is significantly large for the RESET case as it can cause also failures for handover events between outer-outer sectors as the optimized CIO value is reset to default. On the other hand, MRO performance has converged and stabilizes after resolving the handover problems overtime in both cases.

In real network scenario, such types of deployment changes have put a challenge on proper handling of the connection state and maintaining service continuity for the users impacted by the deployment layout change. Such problems are illustrated in Figure 9 where the location of users experiencing the RLF in the network and their connection state transition are depicted for deactivation (Cell-merging) deployment change case. In the figure only the user connection state changes attributed to the Cell-merging are displayed. Accordingly, the UEs used to be located in the inner sector coverage area have lost connection after the change and become in RLF state. Moreover, it has been observed that, around 24% of the users in the considered scenario have experienced such failures and remain disconnected until they are able to establish (re-establish) connection to a target sector as shown in Figure 9 (b). Such types of connection failure problems triggered by deployment change are not MRO problems hence can not be resolved unless additional coordinated mechanisms are employed along with the execution of the desired deployment change, for example enhanced and coordinated user hand-off mechanism and advanced connection re-establishment scheme could ensure seamless layout change while maintaining service continuity to acceptable level.

IV. Conclusion

In this paper, the impact of deployment change has been investigated with respect to user mobility and performance of existing MRO operation considering AAS-enabled Vertical Sectorization scenario. It has been shown that storing optimized CIO values of a certain deployment layout, and fetching and applying the configuration to the network while the deployment layout is restored, can quickly adapt and stablize network performance. Moreover, two extreme ways of treating collected MRO statistics and optimized CIO values of cell being faced with deployment change in the neighborhood are discussed. Furthermore, it has been observed that, proper handing-off users and ensuring seamless service continuity is a challenge during deployment transition when source cell of the surrounding deployment situation. Hence, it is required to have an additional coordinated mechanism and procedure to handle user traffics in a cell(s) going to be further split, or going to be merged or incoming users towards service coverage area undergoing such changes.

References

[1] S.Hamalainen, H.Sanneck, and C.Sartori, *LTE Self-Organising Networks (SON): Network Management Automation for Operational Efficiency*. WILEY, 2011.

[2] D. W. Kifle, B. Wegmann, I. Viering, and A. Klein, "Mathematical model for vertical sectorization (VS) in AAS based LTE deployment," in *11th International Symposium on Wireless Communication Systems 2014. ISWCS 2014.*, Aug 2014, pp. 100 – 105.

[3] 3GPP, "SON for AAS-based deployments, RP-141624," 3GPP TSG-RAN Mettings #65, Tech. Rep., 2014.

[4] O. N. C. Yilmaz, S. Hämäläinen, and J. Hämäläinen, "System level analysis of vertical sectorization for 3GPP LTE," in *6th International Symposium on Wireless Communication Systems 2009. ISWCS 2009.*, Sept 2009, pp. 453–457.

[5] D. W. Kifle, B. Wegmann, I. Viering, and A. Klein, "Impact of antenna tilting on propagation shadowing model," in *2013 IEEE 77th, Vehicular Technology Conference (VTC Spring)*, June 2013, pp. 1–5.

[6] D. W. Kifle, L.Gimenez, B. Wegmann, I. Viering, and A. Klein, "Comparison and extension of existing 3d propagation models with real-world effects based on ray-tracing," in *Wireless Personal Communications Journal, Springer*, 2014.

[7] I. Viering, B. Wegmann, H. Martikainen, A. Awada, and A. Lobinger, "Mobility robustness optimization beyond doppler effect and wss assumption," in *IEEE International Symposium on Wireless Communication Systems 2011*, November 2011.

[8] F. B. Tesema, P. Zanier, I. Viering, M. Simseka, and G. P. Fettweis, "Co-existence of enhanced inter cell interference co-ordination and mobility robustness optimization," in *IEEE International Conference on Communications (ICC)2015*, June 2015.