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A Neighbor Relation Whitelisting Method for Wireless Cellular Systems

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ABSTRACT

By the introduction of new methods such as device to device communications, massive multiple input multiple output systems that operate in millimeter wave bands, vehicle to infrastructure communications, wireless cellular communications systems entered a new phase of their evolution through 5G and beyond. This new paradigm pushes the boundaries of communications further from human device interaction and communicating entities becomes available at every phase or stage of human life. These important changes also come with important problems to be tackled, e.g., optimization of such complex networks in an automatic manner with the least possible human intervention. Moreover, performance of wireless cellular networks should increase to satisfy the increasing capacity demand stemming from new users and applications; the quality of service metrics should be improved everyday. Since it is impossible to achieve such complex and demanding tasks with manual operations, self organizing networks (SON) are emerged to address the optimization issues of wireless systems. One of the main functions of SON is automatic neighbor relations (ANR) which keeps the neighbor relation table of a cell optimal for strong handover (HO) performance. Besides this major task, ANR conducts whitelisting and blacklisting of cells which are the functions with significant impact on the HO performance of a cell under optimization. Thus, in this paper a comprehensive whitelisting method which utilizes histiroc HO metrics and previous blacklisting and whitelisting status of relations in the decision process is proposed. Simulation results indicate a viable increase in the number of the relations whitelisted, thus protected from unintentional deletion or deletion by other optimizing entities working in local i.e., distributed ANR.

Keywords: Automated neighbor relations, cellular wireless networks, self organizing networks

Introduction

Wireless communications systems are passing through a major transformation. Initial works of last century intended communicating people from some fixed locations or at most from their cars. Later mobile communications systems evolved into sophisticated networks which connect devices with each other and even some infrastructure with the machines utilizing them. With the advancements in the semiconductor technologies, communications chips are much smaller than before and they are more effective than their predecessors. Such a paradigm shift also generated a catalysis effect for the evolution of wireless communications systems. Starting from 2G to 3G through 4G technologies and towards 5G systems, the process that wireless communications passes through is also the evolution of optimization of wireless network operations [1]. In order to minimize pre-provisioning during the deployment of a new wireless network or a single base station, and during the active operations of network, administration and maintenance phases, it is necessary to automate the configuration of network parameters. To this end, self organizing networks (SON) provides the operators with the technological means to achieve automated optimization of complex, layered networks with the least possible interaction with humans. Therefore SON can provide reductions in the operating expenses while maintaining the quality of service at the levels that can not be achieved by manual optimization.

One of the main features of the SON is Automatic Neighbor Relations (ANR) that manage the neighbor relations of cells under base stations (BSs) which are kept in the neigbor relation ta-

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ble (NRT) of a cell. NRT can sometimes be overpopulated with unnecessary relations, unwanted relations or relations that are performing poorly in terms of handover (HO). Since the content of NRT is comprised of cells that the source cell (SC) or the cell under optimization conducts HOs, optimization of NRT is an important task and can provide important performance gains [2, 3]. According to the 3GPP documentation [4], ANR can delete relations, add relations, do the blacklisting of relations and whitelisting of relations.

Related Work

When the research on the subject of NRT or neighbor cell list (NCL) optimization is considered, initially, a concept where NCLs are dynamically planned during system operation with little or no manual assistance is proposed in [5] and [6] for 2G systems. The intention was to propose a concept for dynamic planning of NCLs which solves the problems involved with the manual planning. Idea was to let the NCLs be dynamically built, based on the long term behavior of the network. A neighbor list generator is introduced to generate an NCL for each cell based on event statistics and measurements previously collected from mobile or base stations. In [7] a self-optimizing NCL establishment mechanism which utilizes the detected set reporting is proposed for 3G universal terrestrial radio access (UTRA) frequency-division duplexing networks. The missing neighbors were analytically identified based on the corresponding coordinates and events. A rangebased neighbor list optimization algorithm which considers coordinates of every base station and antenna parameters including beam width, main lobe direction, and antenna penalty is proposed for mobile WiMAX systems in [8]. The simulation results showed that as the algorithm complexity increases, better modeling of the cell area is achieved and therefore NCL is optimized more accurately. However, as the complexity increases, the implementation cost and algorithm execution duration also increase. In [9] a similar approach to [8] is adopted for cell coverage area estimation and an automatic NCL update algorithm based on the overlap of coverage area between the newly added cell and neighbors is introduced. Besides, in this study entire process of NCL definition and network adaptation is addressed in the context of LTE networks.

[10] proposed a three layered neighbor list tracking protocol for 3G universal mobile telecommunications systems. The connections between base stations are defined over graphs and the graph relations are held in a compressed form with the help of Boom filters. The process of building the graph is policy-based. This proposed layered approach introduces a robust way of tracking updates on the base stations, however introduces a heavy burden on the system level implementation. Later [11-14] laid down the basics of automatic physical cell identifier selection procedures and ANR functionality in the LTE systems. Reference signal received power (RSRP) metric is used for HO decision purposes and several simulation scenarios are discussed based on virtual deployments. On the other hand, in [15] a visualization tool that visualizes a selforganizing network under the operation is combined with ANR functionality to investigate the details of HO failures and call drops to better understand the reasons behind these events and provide solution in the ANR level.

In [16] a neighbor list management algorithm is proposed for several LTE intra-frequency HO scenarios. Signal strength and number of handovers are utilized as key performance indicators (KPIs). [17] presented a dynamic NCL generating algorithm based on vote model. In this approach every pilot measurement conducted by the UE for each cell has a vote value based on the pilot strength and these values are used as votes to list the neighbor cells in NCL for HO purposes. Coordination of base station measurements are utilized to produce a common NCL for base stations in a given vicinity to eliminate the hidden base station problems at femtocell scenarios in [18]. A method for automatically optimizing a NCL is presented, which consists of an initialization routine at the self-configuration phase, followed by a self-optimization phase that further refines the NCL based on measurements provided by mobile stations during the network operation in [19]. While [20] discussed how to hold GSM neighbor cells in LTE systems, [21] utilized fuzzy logic based inference mechanisms for WCDMA NCL optimization. In this work, general performance event handling (GPEH) records on the RNC are parsed for both undefined/defined neighbors and analyzed via fuzzy rule base criterion.

Simulation results of the convergence time of the ANR function based on A4 event for an LTE network in a dense urban scenario is discussed in [22]. A blacklist method which can significantly reduce measurement overhead in the mobile terminals during the network auto-configuration period is also introduced. Furthermore [23] proposed a dynamic NCL management scheme to enhance NCL convergence and alleviate missing neighbor problems in LTE networks. The scheme gives higher priority to newly detected neighbors over existing ones, ensures fast and accurate NCL updates after radio coverage changes. An algorithm to make minimum but appropriate number of neighbor femtocell lists based on femtocell-to-femtocell HOs is proposed in [24]. A general evaluation of distributed ANR functionality implemented based on LTE 3GPP requirements is provided in [25] for a set of measurement results. [26] also introduced a mechanism to automatically generate an efficient NCL for a new planned GSM or UMTS cell based on ranked overlapping coverage using empirical model calculations. NCLs for cells in a real life network are automatically generated using four approaches which utilize RSRP values and matching coverage information extracted from radio planning, optimization tools and the mobile network databases.

An ANR penetration probability prediction method is proposed in [27] and validated over an LTE network through simulations. ANR penetration is defined as the ratio of NRs established by ANR function to all the NRs in a specific network. The manuscript also derives total time that a UE can use to receive E-UTRAN cell global identifier (ECGI) of the neighbor cell. NCL management and optimization issues are investigated for heterogeneous networks in [28]. The paper presents a practical and standard complaint solution for reducing the size of NCLs by customizing the NCLs for individual UEs. [29] introduced formulation of the NCL optimization problem that evaluates the cells according to their directional share, distance from the cell under optimization and drop calls. The method adds missing neighbors that cause call drops and prohibit the addition of far neighbors since they will suffer from downlink interference. A policy based ANR management approach is introduced for maintaining small cell LTE NRTs in [30]. The proposed mechanism considers load and quality of service (QoS) violation factors of the neighboring accesspoints, in addition to received signal strength reports. The priority of neighboring access point is computed based on combination of signal strength, QoS violation, utilization, and load factors. A conceptual NRT optimization approach is introduced in [31] for LTE based networks based on distance of the neighbor cell from the source cell, HO statistics such as HO share of neighbor cell and RSRP measurements.

In [3] effect of automatic updates to the LTE NRT is evaluated to optimize the effciency of HOs in the network. An algorithm which monitors too early or too late HOs, observed statistics in OAM is proposed. The algorithm updates the NRT to maximize the network throughput and minimize the probability of loss of connectivity. An NCL optimization method is implemented on a real UMTS network for a high interference scenario in [32]. The method considers number of times that a given UE is served by the cell under optimization, received signal code power, and Ec/N0 values as the optimization criteria. An NCL optimization approach utilizing signal to interference ratio (SINR) and HO statistics is proposed in [33] for macro-cell micro-cell scenarios. According to this approach, when the measured SINR of signal by a given UE from a neighbor cell increases above a certain threshold and if the probability of HO to that cell from the serving cell is also above a certain predefined threshold, the given UE updates its NCL to include this cell to the list. If the corresponding cell does not comply with the given criteria, it is removed from the list. In the scope of 5G related ANR works [34] proposed automatic BS relations approach to detect neighbor cells in 5G systems. Downlink, uplink, and link failure procedures are described along with virtual beam relation establishment. [35] has shown utilization of network function virtualization for operating ANR to make it as flexible as possible to adapt the dynamic environment of 5G networks. Massive multiple-input multiple-output (MIMO) technology is expected to improve the capacity and coverage of mobile wireless networks and in [36] NRT implementation is extended to the cases in which massive MIMO beam tracking is conducted in realtime thus assuming that beam pairing relationships are created and dynamically updated between source and target cells. On the other hand, automatic base station relations, automatic wide beam relations, and automatic narrow beam relations are defined for 5G networks considering transmission /reception points (TRP) as extensions to the base stations in [37].

When the current state of standards is considered for ANR, its concepts are included in LTE standards starting from the first release of the technology (Release 8), and expanded in scope with subsequent 3GPP document releases TS 32.511, TS 36.300, TS 32.500. These documents regulate ANR operations in a broad sense such as indicating that ANR feature should be able to add relations to NRT or remove them from NRT, it should have relation and X2 connection whitelisting and blacklisting options, HO allowance and prohibition options. More importantly, the only detailed ANR operations is the discovery of new neighbors via user equipment (UE) measurements for intra-frequency and inter-frequency cases which is a part of distributed ANR (D-ANR) architecture. Thus the scope of ANR feature falls short when the requirements of current and future wireless systems are taken into account [38].

Proposed Method

Even though whitelisting and blacklisting functions are also parts of ANR, the research in the area of ANR focuses mainly on the optimization of NRT and some simplistic approaches based on one dimensional decision processes which depend on a single metric are proposed for whitelisting and blacklisting. Therefore in this paper a comprehensive whitelisting method is proposed for cellular wireless networks. The proposed method takes a variety of metrics extracted from performance management (PM) data comprised of HO criteria and configuration management (CM) settings about the previous blacklisting and whitelisting status of a relation into consideration during its processes.

Automated Neighbor Relations

There are three main ANR architectures; centralized ANR (C-ANR), which is the most common application of ANR, manages the neighbor relations from a centralized perspective by overseeing all the BSs in the region of optimization. Therefore it becomes possible to optimize a set of BSs jointly. Centralized PM and CM data is utilized to generate the key performance indicators (KPIs) and these KPIs are used to make decision by ANR, which is acts a functionality of CANR. In such setting though, it takes time to collect all the data from the BSs and since the decision are done in a centralized manner, the cycle of analyzing data, making decisions, execution of the decisions, observing the outputs of the decisions and making new decisions or reverting the previous actions takes time. Therefore there is a balance between the advantages of centralized decision making by overseeing the general picture and the decision processing time itself. Moreover, C-ANR may incline to make decisions based on instantaneously available information instead of further analyzing the historic data, an additional process that adds more lag to the decision and execution cycle period. On the other hand, when distributed ANR (D-ANR) is available in the local nodes and acting as a separate entity modifying the NRTs, C-ANR has to consider actions taken by D-ANR while conducting some modifications on the area or region of optimization. D-ANR, when available, adds another domain complexity to the operations of C-ANR. It is seen that by the operators some basic whitelisting and blacklisting policies are implemented to make agile decisions based on one dimensional metrics of rate of failed HOs and attempts.

D-ANR is a function of SON which operates solely in the basis of BS. Its decision making and operations are local and they depend on the local KPIs of the cells under the BS. Therefore its operations are agile when compared to C-ANR, however, due to the very limited view of the region of network under optimization, accuracy of the decisions of D-ANR which effect the nodes beyond it works can become problematic for long term operations. Furthermore, while a single C-ANR module manages the region under optimization, number of D-ANR modules required would be decided by the number of BSs under optimization in the region. Running that many D-ANRs can also be cumbersome for some particular topologies e.g., in urban settings. Even there are many D-ANR modules available, their parameter settings should also be monitored and adjusted accordingly since topologically it would not be possible to come up with a single uniform set of parameters which is valid universally for all D-ANRs running on every BS. To the best of the author's knowledge, currently available D-ANR modules do not posses any blacklisting or whitelisting policy; these operations are left to the central decision mechanism if not to the C-ANR module which works in parallel to the D-ANR modules in the nodes. Such algorithms or implementations are not reported in the literature either.

Hybrid automated neighbor relations (H-ANR) is a compromise between C-ANR and D-ANR. In the H-ANR setting some functions that require fast decision making and action which effects a limited part of the network section under optimization is executed by D-ANR modules when they are available or selected to be utilized in some part of the network. However the behavior and the actions taken by D-ANR is closely monitored by H-ANR, when a certain bias occurs, instead of reverting the actions taken by D-ANR, H-ANR modifies the parameters of D-ANR which let to that behavior for an ultimate solution. One step before, when implemented, initial baseline configuration for D-ANRs are also provided by H-ANR based on central information available to H-ANR. Such activities of H-ANR has important impact on the reduction of control plan signaling and manual operational intervention thus reducing OPEX and CAPEX of the operator, independent of the vendor. Secondly, some of the long term decisions are made based on the centralized information available, H-ANR provides the advantages of C-ANR for the critical decisions that require long term data monitoring and prediction. Therefore, H-ANR considers historical data to make decisions about the optimization of network and decision, execution, and revert when necessary states are conducted in a more informed manner, more securely and safely. Such an approach needs more sophisticated algorithms and a more complex ANR module when compared to C-ANR and D-ANR, however, this does not mostly mean the increase of topological network complexity and extra signaling load to the network. The gains achieved by the optimization routines of H-ANR overly compensate the extra load introduced.

Neighbor Relation Whitelisting Method

H-ANR presumes availability of procedures that will make whitelisting decisions viable i.e., tracking of additions to NRT and removals from it are conducted at each run and bookkeeping of these events are done meticulously since additions and removals can also be done by D-ANR and operator besides H-ANR. New neighbors can be added via X2 in 4G and Xn interfaces in 5G. Removals Table for NR is illustrated in Figure 1. This table simply keeps the track of deleted neighbors by recoding when the relation is deleted, who deleted it. The repetitive deletions are tracked by keeping the target cell database identification key since same relation can get different ids when they are added repetitively. Assuming that H-ANR runs over the BS under optimization with the period of *anr_run_time* in a *total_run_time* which is set before the initialization of H-ANR, the number of runs ($N \varepsilon Z^+$) of H-ANR can be calculated by

$$N = \left\lfloor \frac{total\_run\_time}{anr\_run\_time} \right\rfloor \quad (1)$$

If the total number of neighbors in the NRT of a source cell (SC) under the BS under optimization is ($R \varepsilon Z^+$) and the successful HOs to NR $r \varepsilon R$ from the SC in the

Source Cell Db Id Key	Target Cell Db Id Key	Relation DB Id Key	Type	Time of Removal	Who Deleted?
627	46	5626	INTRA	[y:m:day][h:m:sec]/ pm batch time/ timeOfLastModification	D-ANR_DELETE/ Xn_DELETE/ Manual_DELETE
	12	2672	INTER	[y:m:day][h:m:sec]/ pm batch time/ timeOfLastModification	D-ANR_DELETE/ Xn_DELETE/ Manual_DELETE
	786	931	UTRAN	[y:m:day][h:m:sec]/ pm batch time/ timeOfLastModification	D-ANR_DELETE/ Xn_DELETE/ Manual_DELETE

Figure 1. The Removals Table tracks the removed relations from the NRT. Same relations can be added and removed repeatedly. Such behavior can be detected via this table.

$n^{th} \varepsilon N$ run is counted and calculated as $S_{HO}(r,n)$, then normalized HO share of the relation can be calculated by first computing the total number of successful HOs from the SC in n^{th} run is given by

$$TS_{HO} = \sum_{r=1}^{R} S_{HO}(r,n). \quad (2)$$

Therefore normalized successful HO share of NR *r* becomes

$$NS_{HO}(r,n) = \frac{S_{HO}(r,n)}{TS_{HO}}. \quad (3)$$

Instead of utilizing instantaneously available KPIs, H-ANR makes decisions based on the historic change of the available data thus, for all runs until n, normalized successful HOs for the particular relation are

$$NS_{HO}(r) = [NS_{HO}(r,1), NS_{HO}(r,2), \ldots, NS_{HO}(r,n)] \quad (4)$$

and during this time, until the current run the mean value of the normalized successful HOs to NR *r* can be calculated by

$$A\_NS_{HO}(r) = \frac{1}{n}\sum_{i=1}^{n} S_{HO}(r,i). \quad (5)$$

It is also an important KPI that how many of the HO execution attempts are successfully turned to actual HOs. This is a metric which provides information about failed HO attempts indirectly. Even though the HO share is high for a relation, if the attempted HOs are highly unsuccessful, such relation should not be whitelisted and kept under performance monitoring. To that end if the number of attempts for HO executions in n^{th} run to *r* is given but A_{HO} (r,n) successful HO executions can be calculated by

$$RS_{HO}(r,n) = \frac{S_{HO}(r,n)}{A_{HO}(r,n)} \quad (6)$$

and successful HO executions until the end of run are

$$RS_{HO}(r) = [RS_{HO}(r,1), RS_{HO}(r,2), \ldots, RS_{HO}(r,n)] \quad (7)$$

and finally the mean value of the successful HO executions can be written as

$$A\_RS_{HO}(r) = \frac{1}{n}\sum_{i=1}^{n} RS_{HO}(r,i). \quad (8)$$

Please note that the algorithm actively depends on historical recordings that are hold in Blacklisting and Whitelisting Table illustrated in Figure 2. Tracking of all the blacklisting and whitelisting operations to all relations of the SC under optimization is kept in this table since the initialization of the H-ANR operations for the first time. Therefore it is possible to obtain historical tracking of a relation in terms of blacklisting and whitelisting from this table. Each relation can be added to and removed from this table multiple times with different relation IDs at different times. To overcome this problem real database ID of the cell which added as a relation is kept. Therefore recurring operations are also detected. Relations can be whitelisted, blacklisted or their status can be removed. These information are hold in two columns, first, operation, define the operation conducted which can be whitelisting or blacklisting. The second column provides the information about the action whether the relation is released from being whitelisted, which is defined as removed or added to the whitelist, which is added. Same goes with blacklisting operations.

SC Database ID Key	Db ID Key	CellRelationId	neighbor CellRef	Operation	Action	Time of Addition to the list
627	72	EUtranCellRelationId	52	Blacklisting	Added	[y:m:day][h:m:sec]/ pm batch time/ timeOfCreation
	427	EUtranCellRelationId	2741	PLMN Blacklisting	Added	[y:m:day][h:m:sec]/ pm batch time/ timeOfCreation
	279	GeranCellRelationId	9	Whitelisting	Removed	[y:m:day][h:m:sec]/ pm batch time/ timeOfCreation
	427	EUtranCellRelationId	2741	Whitelisting	Added	[y:m:day][h:m:sec]/ pm batch time/ timeOfCreation

Figure 2. The Blacklisting and Whitelisting Table which keeps the tracking of blacklisting and whitelisting of relations. Precise bookkeeping is an important part of H-ANR functionality

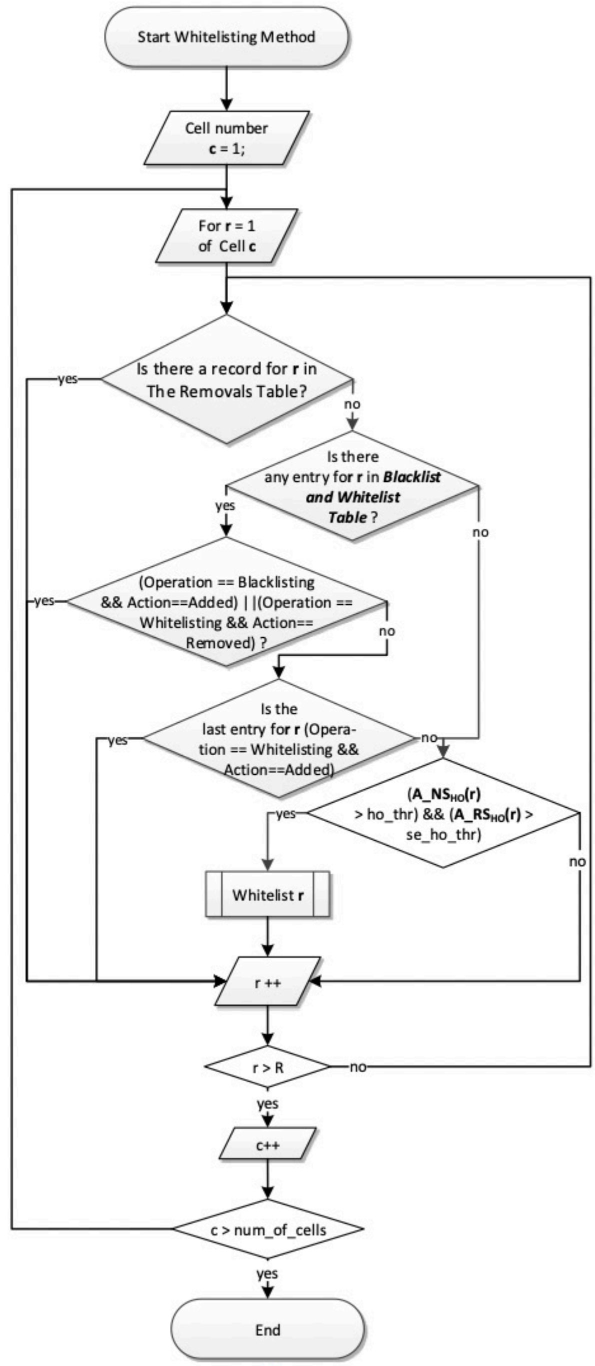

Figure 3. The flowchart of the proposed whitelisting algorithm

H-ANR can be operating continuously or can be activated intermittently, time to time, based on the needs or configuration of the part of the network under optimization. Assuming that the *total_run_time* is the period that the H-ANR will run *N* times, *observation_window* becomes the time frame that back in time, starting from the current time until the time, day, and year that H-ANR considers historic information. Therefore *observation_window total_run_time* is the time-frame that H-ANR goes back, while making decisions.

The proposed whitelisting method is given in Figure 3. Assuming that the number of cells under the BS which is being optimized is *num_of_cells*, which in general is 2, 3, 4, or 6 based on BS configuration, the method starts with the relation *r=1* of the first cell, and from there passes over all relations of all cells for whitelisting. The method first checks for an entry for *r* in the Blacklisting and Whitelisting Table until *observation_window* back in time. If there are entries and at least one of these entries are blacklisting or removal from whitelisting, the relation is passed. The idea is that if the NR is currently blacklisted or even it is not blacklisted now, since in was blacklisted during the *observation_window*, some more time should be given until how the cell behaves understood.

Secondly, if the cell is removed from being whitelisted in *observation_window*, some more observation time is needed to better understand the performance of the NR. If these operations are not encountered, then, it is checked if the cell is already whitelisted, which is trivial. If there are no records for relation in the Blacklisting and Whitelisting Table or the two steps above are confirmed to be false, averaged normalized successful HO share (A_NS_{HO} (r)) for the relation and the average successful HO executions (A_RS_{HO} (r)) compared with HO threshold (*ho_thr*) and successful HO executions threshold (*se_ho_thr*) sequentially. If these metrics for the relation is above the threshold, the relation encloses an important HO share with a high level of successful HO executions, thus should be whitelisted.

Please note that in accordance with the whitelisting method, H-ANR should have a blacklisting functionality for relation banning from HOs, and X2 or Xn blacklisting policy to prevent unwanted relations to pop up automatically through these connections from the neighboring BSs. Furthermore, X2 or Xn interfaces which are not used or rarely utilized in the context of ANR and mobility load balancing should be removed automatically to release some resources to the other functions of the network. PLMN blacklisting should be done to find and remove the relations that are in NRT due to some configuration errors. X2 or Xn whitelisting should be conducted if all the cells of two BSs are mutually whitelisted in their NRTs. Finally, X interfaces which are introduced with 4G are very useful in terms of control plane signaling management since it is favorable for the network operators to shift such signaling from S1 interface to X interfaces due to the optimization gains e.g., rate of HO executions conducted through S1 is aimed to be kept below %10 for an healthy operation.

Simulation Results

The proposed relation whitelisting method is implemented in MATLAB utilizing real CM data covering a cluster of more than 600 BSs and 3500 cells indicated in [38]. From this set, a subset of 100 BSs are selected as a subregion of optimization. The actual CM data is incorporated into MATLAB from Microsoft SQL server environment by utilizing java database connectivity objects. PM data that the KPIs thus the decision metrics are simulated as follows; since whitelisting algorithm considers an *observation_ window*to make decisions, insufficiency of the actual PM data size available is compromised by simulating the PM data based on the distributional characteristics of the real data. First theA_NS_{HO} (r) and A_RS_{HO} (r) metrics are calculated from the real data and their distribution is estimated by Kolmogorov-Smirnov goodness of fit test (K-S test). The best fit for theA_NS_{HO} (r) became the Pareto distribution with $\alpha \varepsilon$ [1.1, 3.2]. Thus the simulation data for all BSs and cells are generated according to Pareto distribution and the during the assignment of values, distance of the BSs from each other are also considered. When the mertic ofA_RS_{HO} (r) is investigated it is seen that the numerical values are in between [0.97,1] with mostly values very close to 1. A data generation sequence is implemented in MATLAB with many runs of data generation and each set is compared with the real measurements. The best fitting extended set is utilized for simulations.

Detailed investigation of the simulation resutls for 100 BSs indicate that the number of newly added whitelists exhibit similar characteristics therefore, instead of providing averaged numerical results, some snapshots of the performance will be given. In

Table 1. Performance of Whitelisting Algorithm when it is run from scratch over BS 1 and BS 2

Base Station Number	Cell Number	Number of Newly Whitelisted Relations
BS 1	Cell 1	6
	Cell 2	4
	Cell 3	6
	Cell 4	6
	Cell 5	5
	Cell 6	2
BS 2	Cell 1	5
	Cell 2	5
	Cell 3	4
	Cell 4	5
	Cell 5	3
	Cell 6	7

this context, two cases are considered in the first place; a) even though the real CM data included in the simulations already have some manually whitelisted relations, reverting back these operations, the algorithm run from scratch, b) keeping the already whitelisted relations coming from CM, observe what the algorithm adds beyond those. Table 1 shows the newly whitelisted relations for the six cells of BS 1 and BS 2, which are selected for the observation of the algorithms. Note that the results of BS 1 and BS 2 repserent average cases and the results of other BSs vary with a narrow standard deviation. The results in the following two tables are given for *ho_thr = 0.05 and se_ho_thr = 0,987*.

Table 2. Performance of Whitelisting Algorithm when it is run by considering already whitelisted relations over BS 1 and BS 2

Base Station Number	Cell Number	Number of Previously Whitelisted Relations	Number of Newly Whitelisted Relations
BS 1	Cell 1	3	3
	Cell 2	3	1
	Cell 3	3	3
	Cell 4	2	4
	Cell 5	2	3
	Cell 6	2	0
BS 2	Cell 1	3	2
	Cell 2	3	2
	Cell 3	3	1
	Cell 4	3	2
	Cell 5	2	1
	Cell 6	2	5

Table 3. Performance of Whitelisting Algorithm when the changes in the HO share threshold is considered.

Base Station Number	Cell Number	ho_thr = 0,025	ho_thr = 0,05	ho_thr = 0,1
BS 1	Cell 1	6	3	2
	Cell 2	3	1	0
	Cell 3	6	3	1
	Cell 4	4	4	0
	Cell 5	5	3	1
	Cell 6	4	0	0
BS 2	Cell 1	4	2	2
	Cell 2	4	2	2
	Cell 3	5	1	2
	Cell 4	6	2	0
	Cell 5	6	1	1
	Cell 6	6	5	0

On the other hand Table 2 provides the resutls for the second case, the already whitelisted relations are kept and they are listed in the third column of the table. Assuming that they are whitelisted, and checking their status, the new additions by the algorithm is given in the last column. Selection of thresholds is also another important factor effecting the performance of the algorithm. Since *se_ho_thr* fluctuates in a very narrow range, the attention is given to the performance of *ho_thr*. Excluding the manually whitelisted relations the performance of the algoritm for *ho_thr* = 0,025, 0,05, and 0,1 are given in Table 3. *ho_thr* = 0,05 puts itself forward as an optimal cut off point.

Conclusion

ANR is an important functionality of SON and the need for a relation whitelisting mechanism is addressed in this paper based on considering metrics such as average normalized HO share, average normalized successful HO executions in the given operating time in addition to historic behavior of the relation, in terms of being blacklisted or removed from the whitelist. The proposed method is implemented in a hybrid approach utilizing real CM data with synthetically generated PM metrics based on real measurements. Such an approach provided the chance to observe how much added by the new method over the already available data, thus number of newly whitelisted NRs are listed along with the relations which were already whitelisted manually. Even though the proposed method provides a mechanism for whitelisting the relations, it is still a need to develop techniques for removal of relations from the whitelists. Such a method should be considered as a part of a general NRT management mechanism which deletes the relations and adds the new one based on an extensive set of metrics including the geographical ones, since making a decision about the removal of a relation from the whitelist would require a more comprehensive insight about the relation's performance.

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