Ping-pong Reduction using Sub cell Movement Detection

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***Abstract*—In this paper we demonstrate an effective way to classify repeated handovers (ping-pongs) in mobile broadband networks. The paper also presents a method that can significantly reduce unwanted ping-pongs in the network. The method combines a sub cell movement detection method and ping-pong detection to decide when it is most effective to apply handover threshold tuning (pinning) without increasing the risk of late or failed handovers. The algorithm was evaluated based on live network measurements.**

Keywords-mobile broadband; ping-pong; movement detection; network management; self-optimization

I. INTRODUCTION

In mobile systems handovers are controlled by evaluating radio measurements performed by the terminal. If the measurement from a new cell becomes better than the old one (plus some thresholds are evaluated), a handover may be initiated. Since measurements fluctuate due to natural reasons, certain thresholds and smoothing are applied. The setting of these thresholds and smoothing parameters are not obvious and may be a subject to optimization. Ping-pong handover is a potentially undesirable phenomenon, in which the terminal performs frequent handovers between the same pair of cells back and forth, in a short time period.

Reduction of undesired ping-pong handovers is an important task of mobile network management. Moreover, in mobile broadband systems like HSPA, or LTE, ping-pongs may have more undesirable impact than for traditional voice services. Mobile broadband users spend more time in active state typically. It is more likely that a ping-pong situation is maintained for prolonged time than during typically much shorter voice conversations. Packet switched mobile systems are also optimized for data transmission primarily; the extra capacity required to serve large number of ping-pong handovers comes with a non-negligible cost. The amount of ping-pong type handovers may account to approx. 40-60% of all handovers based on measurements in numerous networks.

Another negative aspect of ping-pongs is their potentially adverse affect on mobile broadband services. When the user equipment (UE) switches between serving cells transmission is halted for short time, buffer transfer may happen. Delay or throughput sensitive applications e.g., real-time gaming, real-time interactive applications or high-speed file transfer may be harmed due to frequent handovers [1].

The shortcoming of existing ping-pong reduction solutions is that all ping-pongs are treated the same i.e., they are considered bad and should be eliminated. In reality ping-pongs are not equal. The solution to the problem could be optimized better when knowing the ping-pong situation deeper. Most existing solutions [2][3][4] are common in that on detecting a ping-pong handover, they become more and more conservative i.e., they increase some thresholds. As a result, the pinning decision increases the probability of late and failed handovers causing service interruption.

This paper classifies ping-pongs into several categories and applies different actions to different situations. For this, the paper involves a new type of information, which is the terminal mobility on the sub-cell level. There are solutions [5][6][7] which use different types of location info to assist in the reduction of unnecessary handovers but the resolution of these solutions is not precise enough to be sufficiently effective. Also mobility models are used to predict if the UE has a moving or stationary state but these solutions can have significant error ratio [5][8] and operate on a macro scale rather than on a sub-cell level.

The paper is organized as follows. In Section II ping-pong detection and sub-cell level movement detection method is introduced. Section III presents the different classes of ping-pong cases. Finally, in Section IV and V the hand-over elimination logic and its results are presented.

II. PING-PONGS VS. MOBILITY

Due to movement the radio conditions change, and when thresholds change, causing handovers. In this case handovers are necessary to avoid failed handovers. Such handovers may be done repeatedly between the same base stations. If handovers between two cells happens back and forth in an appropriate time user is in a *ping-pong sequence*. Ping-pong can happen naturally, when the terminal is moving, passing buildings, trees and other obstacles. In this case the affect of ping-pong is much less of a concern than if the terminal is doing ping-pongs while being completely stationary. If the terminal is stationary, there is no real need for such handovers. As a consequence of the stationary state, radio signal quality parameters should not change largely, so in this case the network can imply ping-pong restriction actions more safely. For example, stationary users with appropriate signal quality could be pinned to the best cell (by adjusting thresholds for example).

III. PING-PONG CLASSIFICATION

Ping-pongs are not equal. Therefore the combined examination of the users' ping-pong handovers and mobility states may help to classify ping-pongs happening in different conditions. The classification can help to recover the causing factors of ping-pong handovers. Different types of ping-pongs should be handled in different ways, thus the classifications may also help to have the optimal ping-pong reduction method for every case while also keeping the drop statistics of the network at a low level.

Our method detects the difference between stationary and moving ping-pong users, thus threshold optimizations are applied only when necessary. The algorithm also supports ping-pong elimination for the moving terminals as well. It may be counterproductive to control individual terminals by adding restrictions, since it may increase failed handovers. What we suggest is that cells should be monitored for the amount of stationary and moving ping-pongs. If the moving ping-pong statistics are high, it is an indication that the cell borders are set wrong, i.e. many terminals follow paths crossing borders. In this case individual terminal threshold setting is not the best solution, instead, the cell settings should be changed. We propose to invoke a Self Optimizing Network (SON) algorithm in this case, which can much more effectively address this situation e.g., by changing tilt, power or other parameters.

A. Sub cell Movement Detection Method

We use sub cell level movement information to verify whether the terminal is doing ping-pongs while it is stationary or when it is moving actually. Handover is typically based on signal strength measurements, so when ping-pong detection (detection of repeated handovers) is in account, the movement detection methods should use a distinct data source. In our algorithm we use a timing based algorithm, which is available in numerous technologies as terminal measurement, for example in WCDMA it is part of the standardized RRC measurement report [9].

When analyzing the tendentious changes in the timing information among several monitored cells the algorithm we reported in [10] can detect moving terminals with a precision of min. 80 meters. UE calculates the difference (*Tm*) between the arrival times of system frames (SFN – System Frame Number) coming from neighboring cells, compared to its inner clock (CFN – Cell Frame Number). The method is called *SFN-CFN observed time difference*. Considering precision aspects, calculating the timing difference from two base stations (T_{offset}), provides elimination of drifting UE clock.

$$CFN - SFN = Tm$$

$$T_{offset} = (SFN_1 - SFN_2) = Tm_1 - Tm_2$$

As a result sight of at least two cells on different base stations is a minimum requirement.

When UE moves, tendential change should appear in T_{offset} in contrast with stationary state, where T_{offset} should not change. Searching for tendential changes in the timing differences coming from neighboring base stations can denote users as *moving* or *stationary*. With high probability UE can have more than two cells from distinct base stations in sight. Considering that T_{offset} may differ depending on the angle of the base stations where UE is moving between, we can make the following statements:

- *If any pair of the base stations in sight shows detectable change in the T_{offset}, user is moving.*
- *If none of the pairs of base stations in sight shows detectable change in the T_{offset}, user is stationary.*

A network measurement (see TABLE I.) shows that more than 85% of users are stationary when accessing to mobile broadband services. There are some differences depending on the type of terminals and time of the day.

TABLE I. DISTRIBUTION OF USERS BY MOBILITY

User Group	Ratio of Stationary Users	
	Day	***Night***
Smartphone	89%	85%
USB stick	96%	96%
Tablet	91%	99%

B. Ping-pong Detection

We use a simple ping-pong detection algorithm based on the handover history. Since we are interested mostly of mobile broadband users, we focused on HSPA handovers in this paper.

The algorithm records a *ping-pong instance* as a short-sequence of *Cell A* → *Cell B* → *Cell A* within time period T_{pp} (T_{pp} is defined 30 seconds in this paper). When the user's *source* and *target* cell changes back and forth several times, in at least T_{pp} time, *ping-pong instances* are concatenated to *ping-pong sequences*. (This algorithm can be extended to involve more complex ping-pong patterns in a straightforward manner.) Putting together ping-pong detection with movement detection makes combined analysis possible. Two examples are depicted in Figure 1. and Figure 2.

Figure 1. (top) shows HSPA handovers of a stationary user. As a consequence of the stationary state limited number of cells are in sight for the whole time period. Ping-pong handovers occur between *Cell 1* and *Cell 2*. Figure shows a 10 minute period when user was active and performed numerous handovers between the two cells. Figure 1. (bottom) shows the detected *ping-pong instances/sequences* for the user. During the 10 minute period user performed more than 50 handovers. It means a handover was initiated in almost every minute at average causing a degraded service to the user as well as increased load for the network.

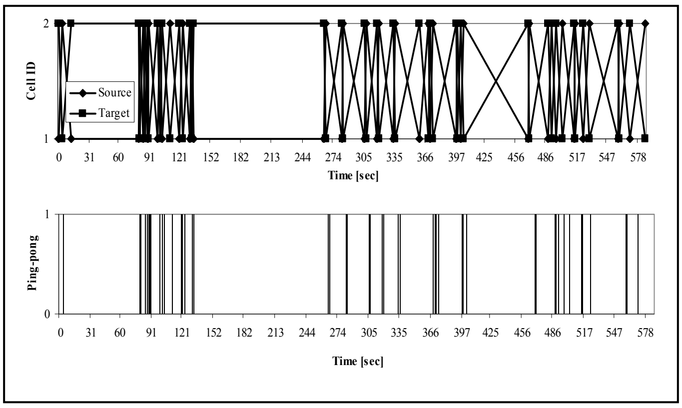

Figure 1. Handover events and ping-pong sequences for a stationary user

Figure 2. (top), on the other hand, shows handovers of a moving terminal while being active for a 40 minute period. As a result of the covered distance, numerous cells were involved in the handovers. Figure 2. (bottom) shows the detected *ping-pong instances* when user passed slowly between cells. Numerous ping-pong handovers were initiated during these periods.

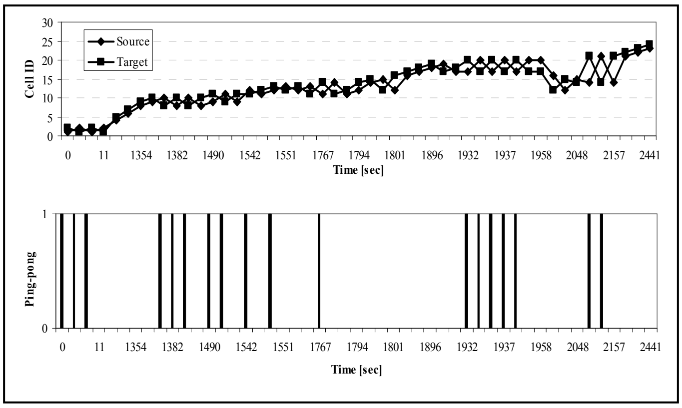

Figure 2. Handover events and ping-pong sequences for a moving user

It is obvious that there is difference between the ping-pongs caused by the moving and stationary users. Stationary ping-pong users can have long ping-pong sequences when the terminal changes between the same two cells. Moving users have shorter ping-pong sequences but number of the involved cells is higher.

C. *Combined Ping-pong Analysis*

First the ping-pong handovers were classified by movement. 73% of the ping-pong handovers were performed by stationary users and 27% by the moving users. For a full classification of ping-pong situations, we also utilize the radio measurements (RSCP - Received Signal Code Power) as reported by the terminals. TABLE II. shows such a classification example based on real measurements.

TABLE II. DISTRIBUTION OF PING-PONG HANDOVERS

User Group	**Ping-pong Handovers**	
	Average RSCP [dB]	***Ratio***
Moving	-83,73	27%
Stationary Low RSCP	-97,68	26%
Stationary High RSCP	-78,86	47%

The table shows that 73% of ping-pongs are due to stationary terminals, but that group can be further divided into two subgroups. Stationary terminals having good signal strength indicate a network tuning challenge, since they could potentially be served in both cells, handover is not really necessary at all. Such ping-pongs constitute to almost 50% of all ping-pongs. Stationary terminals with low radio quality on the other hand should be left to choose the best cell to "survive" or should be commanded to handover to an alternate radio technology potentially.

The moving sub-group should be treated differently. To reduce ping-pongs, they should not be pinned to cells definitely, because that could increase late and failed handovers.

IV. PING-PONG ELIMINATION LOGIC

As we argued, the best actions to eliminate ping-pong may depend on several factors, e.g., sub cell level movement, signal strength, terminal type etc. The actual decision logic is placed in a *decision rule engine*, see Figure 3.

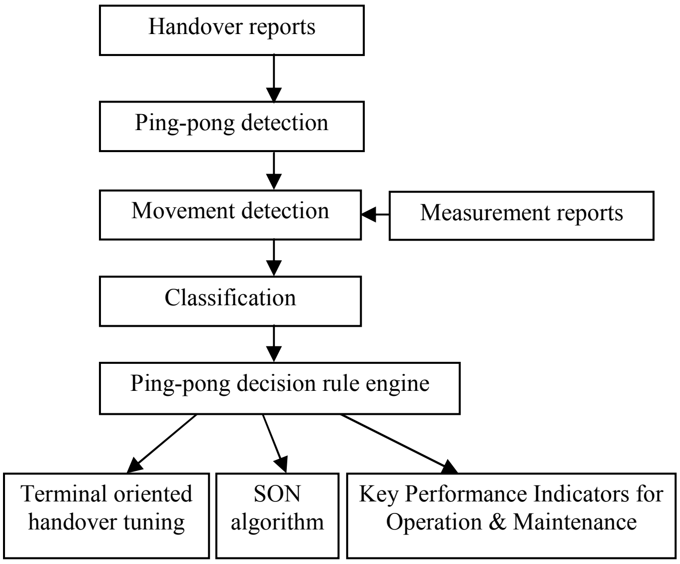

Figure 3. Ping-pong classification decision rule engine

This engine gathers data about users' handover and measurement reports. If handovers happen back and forth in T_{pp} time, ping-pong instance is detected. If instances happen repeatedly they are concatenated to ping-pong sequences and the number of instances is counted for the involved cells. Users with detected ping-pong handovers are sent to the movement detection logic.

If tendential change in the users timing information is detected users state is set to moving, otherwise the state is stationary. After every user passed the ping-pong and the movement detection, results are classified into several groups. There can be several such groups, rules and decisions inserted into the classification depending on further information:

- The policies of the operator
- The service used by the customer
- The customer group
- Terminal type
- Location
- Cell type (macro, micro, femto)

Finally the Ping-pong decision rule engine decides about the necessary actions to take. The actual decision logic should match the operator policies, availability of SON algorithms [11][12], radio technologies etc. Here we just list a few examples based on the arguments presented in earlier sections.

- If there are *several stationary* users causing excessive ping-pong, then a tilt optimization SON algorithm is invoked.
- If a *single stationary* UE is doing ping-pong at good radio conditions in both cells, and the signal strength is within a threshold, it should be pinned to the best cell based on further policies (e.g., load balancing).
- If *a user* is doing ping-pong while being *mobile*, do not pin to a cell, but count such events on a cell level.
- If the *amount of mobile* ping-pongs between the same cells exceeds a certain threshold, then invoke network tuning algorithms, e.g., tilt optimization.

This algorithm thus applies the best ping-pong handling method based on a number of factors.

V. EVALUATION

The evaluation of the advantages of ping-pong classification was based on live network measurements. We first selected UEs who had high number of ping-pongs. Those UEs were classified into moving and stationary subclasses by the movement detection algorithm.

We performed two experiments one aims at showing that dropped calls can be effectively eliminated when reducing unwanted ping-pong handovers, second shows the amount of ping-pong reductions by applying the decision rule engine.

A. Evaluation on the Reduced Risk of Dropped Calls

In this experiment we calculated the probability that the user could still be served in the same cell after time t_s, thus emulating the impact of UE pinning decision on dropped calls. To demonstrate what potentially happens in case of pinning, we choose two users, one moving and one stationary user, see Figure 4.

The stationary user had the same cell in the monitored set with approx. 99% probability even after 2 minutes. This means pinning would not cause a late handover for this UE with high probability. In contrast, for the moving user, the original cell was seen with fast decreasing probability in the monitored set even after a few seconds. For this user pinning would be counter-productive, and would eventually lead to a dropped connection with almost certainty.

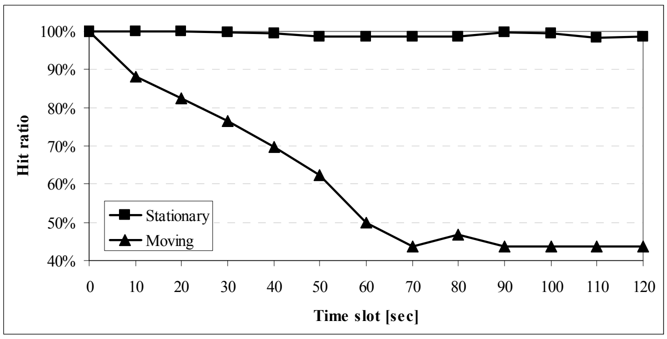

Figure 4. Probability of the existence of the serving cell in the monitored set after time t_s

The above test was also performed for 1700 users randomly selected, from which 20% of users were moving. All users were checked with the mentioned algorithm, if the serving cell exists in the monitored set after t_s (*Time slot*). The cumulative results are shown in Figure 5.

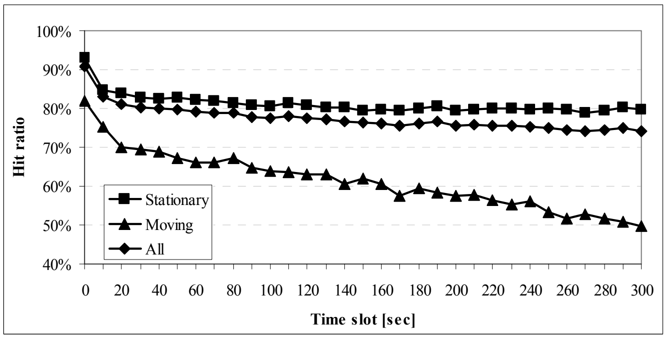

Figure 5. Probability of the existence of the serving cell in the monitored set after time t_s

The evaluation of large number of users gives a more general picture about the difficulties of the ping-pong reduction method in a real network. For example in numerous cases the serving cell doesn't exist even in the next measurement report coming in less than a second, hence the cumulative statistics shown in Figure 5. start below 100%.

Figure 5. shows that there is a significant difference in the decay between *stationary* and *moving* terminals. The ratio of successful pinning seems to be more likely invariant to time in case of *stationary* terminals. In contrast, series representing the group of *moving* users drop down as time goes on.

As a result of the evaluation we can state that there are numerous users, where the neighboring cells are permanently in sight and this is a consequence of the stationary state.

B. Evaluation of the Ping-pong Reduction Algorithm

The previous experiment proved that without movement detection the conventional pinning algorithm would cause large number of dropped calls. We also showed previously that there are numerous users where radio conditions don't allow any threshold tuning optimizations.

In our third experiment, we evaluated how much ping-pong can eventually be reduced without harming the drop statistics. Based on the arguments in Section IV and V-A, pinning is only applied to those stationary UEs in good radio conditions.

In addition, pinning is only enforced until the difference in signal strength between the best and the second cell exceeds a certain threshold T_{H0}. (We used T_{H0} = 2 dB to ensure good mobile broadband experience, instead of the previously set 1 dB threshold.) For the evaluation the same statistical set was used as in the previous experiments.

Our result shows that the number of ping-pongs could be reduced with as much as 70% for the candidate users. According to previous results this can result the number of handovers drop down with 15% on the network level. It is obvious that even more reduction is possible with the larger increase of T_{H0} [13][14] but that could harm the drop statistics and the end-user throughput.

CONCLUSION

This paper presents a ping-pong reduction algorithm, which takes terminal sub-cell mobility detection into account. The algorithm classifies terminals into subgroups, and applies the most suitable algorithm. The algorithm has been evaluated based on real network statistics and showed that a ping-pong reduction of 70% is achievable for applicable users while not increasing the probability of failed handovers significantly.

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