Abstract – MBMS bearer services can be provided in each cell by either Point-to-Point (one Dedicated channel for each User Equipment (UE)) or Point-to-Multipoint (one Common channel shared by all the UEs) transmission mode, but requires a decision to be made between the two approaches. As defined in 3GPP TS 25.346 specifications, this decision is made by the Radio Network Controller (RNC). Thus far, the fundamental criterion used to make this decision has been the number of MBMS users in a Cell. Periodically and on a per Cell basis, the RNC counts the number of MBMS users and based on an operator-predefined threshold, establishes a P-t-M transmission mode, if the number of counted MBMS users in a Cell exceeds this threshold, or a P-t-P transmission mode, otherwise. In this paper we extend our previous work (recently standardized in 3GPP TS 25.922 v7.1.0), which uses the power transmitted by the Base Station (BS) as the channel switching criterion (Power Counting). We evaluate our approach in an MBMS enabled environment and illustrate its capability to dynamically adapt to continuously varying cell conditions by selecting the transmission mode in a more efficient way, preserving in this way the network’s resources. At the same time we demonstrate the limitations of the conventional approach, in terms of radio resource efficiency. We show that by having the actual Cell capacity as the limiting factor (power used by the BS) we achieve optimized capacity during the transmission of MBMS bearer services in UTRAN.

I. INTRODUCTION

Multimedia Broadcast Multicast Service (MBMS) [1] is a new unidirectional (downlink only) bearer service introduced in UMTS (Universal Mobile Telecommunication System) Release 6 specifications [2] in which the same data is transmitted from a single source entity to multiple recipients allowing the network resources to be shared. According to [1], for radio resource efficiency, MBMS bearer services can be provided in each cell by either Point-to-Multipoint (P-t-M) or by Point-to-Point (P-t-P) transmission, but requires a decision to be made between the two approaches. This decision is made by the RNC. With the P-t-M transmission one Forward Access Channel (FACH) is established and shared by all the UEs in the Cell while with the P-t-P transmission one Dedicated Channel (DCH) is established for each UE in the Cell.

Briefly looking into the characteristics of P-t-P and P-t-M transmission modes used to efficiently deliver MBMS content we can see that: P-t-M transmission uses a single channel covering the cell up to the edge and transmits identical traffic to UEs receiving traffic in P-t-M mode. The traffic is transmitted in a multicast manner (one-to-many, but not all) over this channel, i.e. it is not duplicated for each UE. The transmitted power for this channel is fixed and independent of the number of UEs, as there is no power control, but rather it is preset to ensure coverage up to the cell edge. Then again, with P-t-P transmission identical traffic is transmitted to each UE since each packet is duplicated and sent over each DCH established connection. DCH has the capability of power control, that is, the transmission power is adjusted accordingly to provide the required strength to reach the UE. Moreover, because of the independent channel, individual ciphering and QoS control are also facilitated.

Bearing in mind the aforementioned one may conclude that P-t-M transmission is efficient only when a large number of UEs belonging to the same multicast group is present in the cell, but is inefficient when used by a small number of UEs, especially when located close to the BS. On the contrary, P-t-P transmission is efficient when used by a small number of UEs, but inefficient when used by a large number of UEs. However, the number of UEs and their location in a cell is time-dependant and can vary according to UE’s mobility patterns. Nevertheless, idle UEs may join an ongoing MBMS session while others decide to leave. This greatly impacts on the BS’s total transmitted power. Consequently, even if one transmission mode is used initially, a switch to the other transmission mode (and vice-versa) may be required to achieve efficient system operation. Given that transmission mode switching is essential, careful selection of the most efficient switching criterion must be employed.

The rest of the paper is organized as follows: Section II highlights the inefficiencies of the current mode switching approach and discusses certain limitations that need to be addressed. Section III describes the Power Counting algorithm and how it addresses these limitations. Section IV provides a thorough performance evaluation of both schemes to illustrate optimized capacity gains when the Power Counting algorithm is employed. Finally, in Section V, conclusions and future work are presented.

II. PROBLEM STATEMENT

A popular approach for switching between P-t-p and P-t-M (and vice versa), mainly due to its simplicity of implementation, has been the UE Counting approach (see [1]), i.e. the switching criterion is the number of UEs present in the cell and belonging to the same multicast group. This threshold is predetermined and it is often estimated by assuming that all
UEs are distributed uniformly across the cell. This is not a realistic approach because mobility and current location is not taken into account. As a result, UE Counting suffers from the fact that it can not address varying cell conditions whether these are translated as moving UEs or altering fading circumstances, both resulting in BS’s transmitted power fluctuations. But even in situations when UEs are static, this doesn’t necessarily mean that they are uniformly distributed, i.e. some UEs could be located near the cell edge, while others near the BS. Imagine a scenario where all UEs participating in an MBMS session are located near the BS and their total number exceeds that of the predefined threshold justifying a P-t-P to P-t-M switch. FACH transmitted power sufficient to serve UEs residing on the cell edge would be employed resulting in inefficient utilization of the network’s resources. The opposite scenario with the UEs located near the cell edge and their total number being less than the predefined threshold (hence in P-t-P mode, with multiple DCH connections up the cell edge) will also result in wasteful utilization of the network’s resources (see section IV). It is worth noting that similar power considerations exist when crossing cell boundaries and handing over to P-t-P or P-t-M cells [10][11].

Another important factor that needs to be examined is the possibility of the ping pong effect that could cause unacceptable signalling load in UTRAN, additional signalling load for physical channel reconfiguration via the air interface, and possibly even a further QoS degradation just because of the fact that a cell transmission mode switch is executing. The ping pong effect occurs when a switch between P-t-P and P-t-M takes place in short time intervals. A possible scenario triggering a ping pong effect could involve a problematic UE joining and leaving an MBMS session. If this particular UE at the same time adds up with the rest of the participating UEs to match the predefined numeric threshold set for a switch, each time the UE joins or leaves the MBMS session, a switch will be triggered. This loop of switches can be described as a ping pong effect, clearly not a desirable outcome.

In general, finding an optimum threshold for triggering a transmission mode switch using the UE Counting algorithm is not feasible, since no mechanism exist that would allow tracking the state of the network at all times, thus deciding an efficient threshold.

III. POWER COUNTING

With the above considerations in mind, we proposed a new algorithm in [3][4] and further enhanced comprehensively evaluated it in an MBMS setting in this study. Similar ideas progressed to standardization in 3GPP TS 25.922 v7.1.0 [5] and were also investigated by other research groups [6].

The proposed algorithm takes into account the implications and addresses the drawbacks of the UE Counting algorithm in order to deliver a capacity-efficient algorithm providing acceptable QoS in terms of reliable MBMS content. Power Counting uses a different criterion from traditional UE Counting methods for mode switching: The total transmitted power by the BS (hence Power Counting). That is, during an MBMS session, the total transmitted power required to serve all participating UEs when DCH connections are established is continuously measured (FACH power is constant) and the decisive factor which triggers a mode switch is which transmission mode involves the minimum transmission power, thus maximizing capacity.

A primary assumption considered in Power Counting is that when an MBMS session begins, the participating UEs are initialized in P-t-P mode. This is done because we assume that a group is more likely to have a small number of UEs participating at the beginning of an MBMS session rather than large one. After initialization, the RNC decides if it is better to switch to P-t-M or remain in P-t-P mode.

The originally proposed algorithm [3] made a switching decision by taking into consideration the continuous average of power over the most recent interval of width equal to a “window” of 5 sec (smoothed using a moving average filter).

We used a moving average in order to minimize the probability of unnecessary switches due to sudden increase of the power in DCH channels. The moving average aimed to efficiently handle undesirable ping pong effects. The selection of a 5 sec update period was based on the assumption (derived from empirical estimation) that UEs position can change significantly within this particular interval. However, the implementation of the algorithm presented here introduces adaptivity to address limitations of this approach, as described later: instead of considering the moving average over a fixed period, we compute the instantaneous power periodically (Period $T$) and address the possibility of a ping pong situation by introducing a parameter which defines the minimum inter transition time between two consecutive switches. In a similar way, we gain control over the periods that a switch is triggered and successfully tackle the ping pong effect.

Period $T$ is an important parameter playing a key role in Power Counting algorithm’s efficiency. Consider a pedestrian environment Cell serving UEs moving with an average speed of 5km/hr. Setting $T = 5$ seconds might prove efficient in such a Cell as the UEs cover a total distance of less than 7 meters in this period. However, the same period is significantly inefficient in vehicular environment Cell where UEs are moving with an average speed of 120km/hr, thus covering 167 meters in 5 seconds, resulting in greater variations on the downlink power required. Therefore, the selection of Period $T$ should be depended on the Cell’s environment and be a function of the UEs’ speed. For this research we select a Period $T$ of 5 seconds (since in all the scenarios simulated only pedestrian speeds are used), however its fine tuning is a matter of ongoing research.

When using the Power Counting algorithm a switching decision occurs if the following conditions are met:

- If in P-t-P transmission mode and the estimated instantaneous DCHs total power (see below on how this is estimated) is 10% higher than the FACH power (the FACH power is known, as it is constant for a specific cell size) then a switch to P-t-M transmission mode is initiated.
- If in P-t-M transmission mode and the estimated instantaneous DCHs total power (see below on how this is estimated) is 10% less than the FACH power a switch
to P-t-P transmission mode is initiated.

Besides being a second measure, which in conjunction with the inter transition time parameter attempts to eliminate unnecessary switching (ping pong effect), this hysteresis zone introduced (equal to 10% of the FACH power) also aims to reduce traffic overheads due to a mode switch when the gain in power is not sufficient.

The DCH total transmitted power is the only metric that our algorithm needs to compute, since the power of the FACH channel is known and constant. When in P-t-P mode it is easy to calculate the instantaneous total power of the DCH channels since the Base Station (BS) is aware of the downlink transmitted power used for each P-t-P link. Thus the power summation of all channels participating in P-t-P mode is periodically reported to the RNC, which then checks if the condition for switching to P-t-M transmission mode is met. On the other hand, when in P-t-M mode and given that the only established connection is that of the FACH channel, the question which rises is how we estimate the instantaneous downlink power of the DCH connections since there is not any information about this in the BS. To address this, we use the same approach used by the downlink open loop power control [7]. With this approach, upon initiation of a recounting procedure by the RNC[1], the UEs will send received Ec/No CPICH signal strength measurement reports to the RNC. Upon receiving all the measurements reports the RNC estimates the instantaneous downlink power that would be required for a P-t-P transmission mode by using the formula defined below:

$$P_{Tot\_Tx} = \sum_{i=1}^{N} \left\{ \frac{R \times (Eb/No)_{DL}}{W} \times \frac{CPICH_{\_Tx}}{CPICH(\_Ec/No)_{\_i}} \times \alpha \times P_{Car} \right\}$$

Where:
- $N$ is the total number of the UEs receiving the MBMS Service in the P-t-M Cell
- $R$ is the MBMS Service bit rate
- $(Eb/No)_{DL}$ is the DL planned Eb/No value set during the Radio Network Planning (RNP) for achieving a certain Bit Error Rate as to satisfy the required QoS
- $W$ is the chip rate (3.84 Mcps)
- $CPICH_{(Ec/No)\_i}$ is the measurement report received from UE $i$
- $CPICH_{\_Tx}$ is the initial power used for the transmission of the CPICH
- $\alpha$ is the orthogonality factor
- $P_{Car}$ is the carrier power measured at the Node_B and reported to the RNC

IV. PERFORMANCE EVALUATION

For the performance evaluation OPNET Modeller 11.0.A UMTS module [8] was used as a base for building the MBMS simulator [9]. The performance was evaluated by comparing the amount of the total downlink power (capacity) that becomes available when the Power Counting algorithm is used instead of the existing 3GPP UE Counting based on [1]. In order to illustrate the performance, the feasibility and the usefulness of the proposed approach a series of three scenarios have been simulated. Emphasis was given in mobility aspects and varying number of UEs participating in an MBMS session.

A. Scenario 1: Inter-Cell mobility - UEs moving from an adjacent cell to a P-t-P highly loaded cell

Scenario 1 considers the case where a group of five UEs are moving from Cell 1 to Cell 2 (both initialized in P-t-P transmission mode) following the trajectory depicted in Figure 1, with a speed of 5 Km/h. All the UEs are receiving an MBMS Streaming video of 64 Kbps. The coverage of the cells is 1 Km and the propagation environment used is “pedestrian outdoor”. Three instances of this scenario have been simulated in order to illustrate the gain of the Power Counting over the UE Counting algorithm. In the first instance, the UEs (a number of twenty-nine UEs) are uniformly distributed in Cell 2, in the second instance the UEs are located near the Cell’s edge, while in the third instance, the UEs are located near the BS. The results collected are illustrated in Figure 2 - Figure 4. The threshold for UE Counting switching is taken to be 34 UEs, which is the ‘optimum’ number chosen according to the scenario where UEs are uniformly distributed in the Cell.
both algorithms execute the channel switching efficiently. However, the case with UE Counting is that the transmission mode remains in P-t-M mode since the number of the UEs meets and exceeds the condition to have a P-t-M transmission mode. This causes a significant amount of capacity waste since the UEs during their mobility towards the BS reduce the amount of power required considerably, making the use of a FACH redundant. Then again, the Power Counting algorithm, due to its capability to dynamically adapt to the continuously varying Cell conditions (e.g. UEs mobility towards the BS), selects the most efficient transmission mode, resulting in significant power savings, thus maximizing capacity.

The capacity efficiency of the Power Counting is also depicted in Figure 3 (where the UEs are located near the Cell’s edge). As illustrated in this case, the initial power used in the Cell varies between 4 and 4.9 watts. In this case the P-t-M mode is obviously the most efficient one (since the FACH allocates only 2 watts); the UE Counting algorithm keeps the transmission mode to P-t-P, until the number of the MBMS UEs in the Cell is high enough in order to trigger the channel switching. The channel switching is finally executed at the 12th minute of the simulation having reserved up to 6 watts of the total power of the BS. Then again, this waste of capacity is avoided when the Power Counting algorithm is adopted, by establishing a P-t-M bearer in the Cell from beginning of the MBMS Session. On the other hand, as illustrated in Figure 4 (where the UEs are located near the BS), the Power Counting algorithm, in contrast with the UE Counting, not only achieves efficient capacity, but also eliminates the need of channel switching, thus resulting in less signalling overhead.

B. Scenario 2: Intra cell mobility - UEs moving towards the cell edge and back.

The second series of simulations includes a single cell serving 39 UEs. Eleven UEs move with a trajectory pointing to the cell edge and back (Figure 5). Our aim here is to depict the ability of the Power Counting algorithm to dynamically adapt to the varying conditions within a cell, likely to occur in real life deployed MBMS-enabled environments. In addition, the scenario aims to highlight the inability of the UE Counting algorithm to deal with such kind of changes in a cell. Again, for evaluation purposes, simulations (incorporating parameters described in scenario 1) were conducted both for UE Counting (two cases with threshold set to 50 and 30 respectively) and Power Counting algorithms. As discussed earlier in Section II, there exists no way of tracking the state of the network, thus selecting an optimum threshold at all times for the UE Counting algorithm. Therefore, the above thresholds are chosen aiming to depict both possible transmission modes (P-t-P and P-t-M). As the UEs moves towards the cell edge and the distance away from the BS increases, the power required for a DCH established channel increases accordingly. The opposite happens once they start moving towards their original location closer to the BS. The results are displayed and analyzed in Figure 6–Figure 8.

C. Scenario 3: New UEs joining an ongoing MBMS session

In this scenario (see Figure 9), we have one cell serving 34 UEs. Thirty one of them are receiving MBMS multicast traffic (video streaming), while at the same time three are idle. The idle UEs join the MBMS session at the 450th second of the simulation. Similarly to the above scenarios, simulations are carried out both for UE Counting (two cases with threshold set to 50 and 33 respectively) and UE Power Counting algorithms.
power gain is attained in all simulated scenarios. Furthermore, the UE Counting approach is highly susceptible to the ping pong effect since no mechanism is proposed to prevent such incidents and a single UE, joining or leaving a session, may trigger consecutive cell mode switches. More importantly, adding a deadzone based on the UE count will make this approach even more inefficient.

The results presented above demonstrate substantial capacity gains when the Power Counting algorithm is employed. Further enhancements incorporate fine tuning of the periodicity instantaneous power is measured (Period T) in different environments, as well as more comprehensive tests.

Given that a power based approach could be undertaken during inter-cell mobility, namely “MBMS handover” [10], [11] future work is also directed towards combining both approaches into a novel power preserving scheme optimizing system capacity in MBMS mode.

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