Quality Based Handoff in DVB-H Systems Assisted by Cellular Network

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Abstract—This paper introduces a novel seamless handoff approach for DVB-H networks aimed at reducing the user terminal power consumption and at making the handoff algorithm be driven by the quality of the user received signal. This implies the substitution of standard RSSI-based procedures with a method based on the Modulation Error Rate (MER) monitoring. The additional use of an underlying cellular network, for DVB-H related data delivering, allows to achieve additional advantages: a superior power saving and a faster handoff execution. Obtained results suggest that the DVB-H handoff protocol design is an issue, which definitely deserves further investigation in the view of making DVB-H an effective solution for delivering broadcast content to mobile users.

Keywords- DVB-H, Power saving, Handover Management, MER, Dual Mode Terminal.

I. INTRODUCTION

Nowadays, Digital Video Broadcasting to Handheld (DVB-H) standard [1], [2] has enabled the delivery of live broadcast television to mobile handheld devices. DVB-H has been conceived as an evolution of DVB-T, introducing new features in physical and data link layer to overcome the major limitations of DVB-T standard. In fact, DVB-H improves error resilience and reduces battery power consumption through time-slicing (according to which data transmission is bursty); this feature allows the receiver to be switched off during inactive periods (called Off-Time periods). The DVB-H network is characterized by a cellular structure; as a consequence, handoff procedures are a key issue to avoid the service interruption while the user roams across the cells. In DVB-H systems, mobility and handoff management is even more complicated compared to cellular systems, due to the DVB-H broadcast and unidirectional nature.

One of the main issues in DVB-H systems is relevant to the reduction of battery power consumption during handoff. In fact, seamless handoff is made possible only because during the Off-Time the inactive receiver terminal can be turned-on to obtain RSSI (Received Signal Strength Indicator) measurements from neighboring cells. The purpose is to compare them with the RSSI values measured from the serving cell and, finally, to decide whether a handoff execution is necessary or not. Obviously, the higher the number of measurements, the greater the power consumption of the mobile terminal. In our previous works [3], [4] we demonstrated that the user terminal power consumption can be reduced by making the user received signal quality drive the handoff algorithm. This implies the adoption of a method based on the constant monitoring of the Modulation Error Rate (MER), instead of standard RSSI-based procedures. MER is widely accepted as a quality indicator parameter in DVB-H system; therefore, “MER-based” handoff is synonym of “quality driven” handoff. The focus on MER allows us to achieve a reduction in the number of times RSSI measurements are necessary during the Off-Time, and, consequently, also in the relevant signaling load and in the energy consumption. Advantages obtained though this policy are [3]: (i) a more accurate estimation of the received signal quality, (ii) the activation of handoff procedure only when it is actually necessary, (iii) a significant reduction of ping-pong effect with a consequent power saving. In this work, we extend our early idea to the case of handheld terminals equipped with both DVB-H and cellular (i.e. GSM/UMTS network) access capability (dual mode terminals, in the remaining part of the paper). We will show that the joint use of DVB-H related information (conveyed by the cellular network) and MER measurements/predictions allows us to speed-up the handover execution procedure while observing a reduction in power consumption (achieved by avoiding unnecessary RSSI measurements/synchronizations from/to adjacent cells).

The remaining part of this paper is organized as follows. Section II gives a brief overview of MER measurements and highlights the positive effects of the choice of basing our handoff decision on the estimation of MER. The use of cellular network to deliver DVB-H related information is analyzed in Section III, while Section IV illustrates the approach proposed to reduce the power consumption during handoff in DVB-H systems assisted by cellular network. The main results of a simulation campaign, carried out to test the robustness of the proposed policy, are reported in Section V. Conclusions are given in Section VI.

II. HANDOVER MEASUREMENT BASED ON MER ESTIMATION

The DVB-H handover procedure can be summarized in three different phases: (i) Handover Measurement; (ii) Handover Decision; (iii) Handover Execution [2]. During the first phase the signal strength from serving and adjacent cells is

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measured; the obtained values are used during the Handover Decision to select a new candidate signal for Handover Execution. Therefore, the efficiency of a DVB-H seamless handoff algorithm is tied to the prediction of the exact moment in which it is necessary to trigger the Handoff Measurement procedure. The approach we propose uses MER as a metric to evaluate the exact time when an handoff event is required. It allows to trigger the energy-wasting RSSI measurement phase (on both the serving cell and the adjacent cells) only when it is actually necessary. In fact, RSSI measurements are performed only when the user perceives that the transmission quality (strongly related to MER) falls below a minimum acceptability threshold. Actually, we use a MER prediction technique and trigger RSSI measurements when the predicted \( \text{MER}_{n+1} \) value trespasses this threshold at the instant \( n+1 \).

The positive effects of the choice of basing our handoff decision on the estimated \((n+1)^{th}\) MER value instead of the measured instantaneous \(n^{th}\) MER value are listed below:

- Predicted value contributes to obtain an additional safety margin and critical situations that may bring to service interruption are, thus, reduced;
- Comparing the \((n+1)^{th}\) MER value with the threshold is important because RSSI measurements may be urgently required during the Off-Time just following the \(n^{th}\) sample;
- Furthermore, even if the instantaneous \(n^{th}\) MER gets a pre-critical value, the MER trend may still remain rising, this meaning that no handoff measurement is actually required.

By starting from \(k^{th}\) buffered MER samples, \(\{\text{MER}_{(n-k+1)}, \text{MER}_{(n-k+2)}, \ldots, \text{MER}_{(n)}\}\), the value of the next MER at instant \(n+1\), namely \(\text{MER}_{(n+1)}\), is estimated. In the present work, estimation is performed through a least-square parabolic prediction technique. The choice is driven by the good prediction results this technique exhibits in terms of prediction error minimization. Optimal prediction means dramatic reduction of the prediction error, however, optimization of the prediction process is not a focus of this research work and future studies will aim at choosing the best predictor that optimizes the performance.

III. USE OF CELLULAR NETWORK TO DELIVER DVB-H HANDOFF-RELATED INFORMATION

As already discussed in the introduction, our proposal foresees the use of dual mode UMTS/DVB-H terminals. Moreover, in our scenario, a new entity called “RNC-DVB-H data broadcaster” is implemented within the UMTS network. It collects, processes, and delivers to the specific user terminal (by means of UMTS broadcasting channels) additional information about the DVB-H topology network (named DVB-H Handoff-Related Information). In fact, DVB-H standard uses NIT and INT (IP/MAC notifications) tables to broadcast information about network topology and to assist the user terminal during the handoff decision. DVB-H Handoff Related Information are used together with IP/MAC notification to make the handover procedure management more efficient in terms of power consumption. These choices are justified by the following considerations:

- The majority of DVB-H receivers on the market are actually dual-mode DVB-H/UMTS terminals; therefore we could exploit the benefit of “network cooperation” at no additional costs.
- Cell-broadcast-channel [5] in 2G/3G networks is widely used to broadcast various information (weather and traffic reports, network identification, public alerts, etc.) to mobile user served by a particular cell. Adding DVB-H handoff related messages is straightforward and neither it requires additional transmission power nor it uses supplementary UMTS radio resources.
- There is no increase in power consumption in multimode user terminals: UMTS front-end, during normal operation (i.e. when UE is connected to a cell) is already switched on to receive paging and “cell-broadcast-messages”. Moreover, DVB-H Handoff-Related Information are centrally processed and broadcasted by the novel network entity (using downlink direction), thus requiring no interactive return channel between dual-mode terminals and UMTS radio access network.
- UMTS cells are noticeably smaller with respect to DVB-H ones. This means that each UMTS cell could broadcast handoff Information with a severely reduced granularity with respect to DVB-H ones. It will be shown that these additional information are particularly useful in both supporting fast and seamless handoff and reducing unneeded ones.

DVB-H Handoff-related information could be acquired in two ways: (i) “statically”, by special measurement terminals during drive test activities in either the pre-launch or in the optimization phase of DVB-H network (this measurements, geo-referenced, are then offline processed and loaded into RNC-DVB-H data broadcaster); (ii) “dynamically”, by using special equipped dual mode UMTS/DVB-H/GPS terminals that constantly measure DVB-H parameters and periodically transmit them to RNC-DVB-H data broadcaster through UMTS interface, used as return channel. As a helpful side effect, this feedback information is of great interest to network operators as it gives a real-time “snapshot” of the perceived quality of DVB-H networks.

Some of the DVB-H Handoff-Related Information are summarized below. They are valid only within the coverage area of the UMTS cell, which the terminal is served by:

1. **Fake signals list**: This is a list of “fake signals” (frequency, cellId, NetworkId) [5] received in the current UMTS cell and built by the addressed testing terminals. Through the received list, the terminals know which “at risk” channels shall not be used.

2. **Neighboring List**: This is a list (cellId, frequency, coordinates) of all the adjacent DVB-H cells that could be received in the current UMTS cell. This list is noticeably smaller than the one transmitted by NIT and contains only the DVB-H cells adjacent to the actual
user position. In other words, they represent the “handoff candidate cells”. This allows reducing the number of RSSI measurements and speeds up handover execution.

3. Border Cell: It is a flag indicating whether the current UMTS cell is placed along the border of the overlying DVB-H cell. Users in a normal cell (i.e. not a border cell) are within the full coverage of the current DVB-H cells; therefore, a temporary decrease in the perceived quality shouldn’t necessary lead to a handoff as the user is still connected to the best serving cell. Joint Neighboring List and Border Cell information avoid unnecessary handoff and ping-pong effects improving battery consumption.

Users receive and regularly update information from RNC-DVB-H data broadcaster (an update is also triggered when the user moves from an UMTS cell to another one). By means of the received DVB-H Handoff-Related Information, each terminal builds a priority list of the candidate cells to be used during handover execution. This list is a subset of the possible adjacent cells that helps in reducing the handoff execution time (seamless handoff) and reduces the power consumption.

IV. QUALITY BASED HANDOFF ASSISTED BY UMTS

Our Handoff procedure is characterized by the following features: (i) MER measurement are used during ON-Time to evaluate the quality level and received data are buffered in the terminal receiver in order to be used by the predictor module when necessary. (ii) The terminal obtains from RNC-DVB-H data broadcaster (dual mode-terminal) the local DVB-H handoff-related information; (iii) MER measurements are processed by a prediction module, which, on the basis of the predictor output and the received DVB-H handoff related data, takes its decision on the Handoff Management. (iii) if an handoff is triggered, the information attained from the cellular network is used to improve the overall execution. Handoff operations are summarized below:

State 1: Measurement and data collection.

During every ON-Time the user equipment performs the MER measurements only on the serving cell and stores these values into a register. The measured MER value is compared with a threshold $Th_{CR}$ (it is the MER value below which the reception is too bad). A state transition is based on both the measured MER value and the context information received from UMTS:

- if $MER > Th_{CR}$
  $\rightarrow$ Jump to Data Analysis (State 2);
- if $MER < Th_{CR}$ and “UMTS cell is NOT a border cell”
  $\rightarrow$ Jump to MER Prediction (State 3).
- if $MER < Th_{CR}$ and “UMTS cell is a border cell”
  $\rightarrow$ Jump to Handoff Execution (State 4).

Comparing the most recent measured MER value with $Th_{CR}$ reduces the number of times the DVB-H terminal have to execute the prediction process (Step 3); thus minimizing the power consumption. Checking whether user is in a border cell or not, allows to improve the algorithm functionality. If $MER$ falls below a critical value and the user is not in a border cell (i.e. when quality, on the average, is very good), then an unnecessary handover procedures may be triggered; thus, an additional test (MER Prediction - see State 3) is performed to evaluate whether the decrease in the perceived quality is temporary or not. Directly using (also in state 1) predicted MER values instead of a measured value could lead to better results in terms of overall reduction in HO execution. On the other hand this would cause a frequent triggering of the predictor module with an increase in power consumption. Preliminary analysis (not shown in this paper) confirm that only a negligible reduction in HO execution follows the intensive use of the predictor module; this is why we decided to introduce it only in state 3.

State 2: Data Analysis.

The MER value is compared with a different threshold, $Th_{MER}$ (representing the MER value above which the signal quality is optimal; values below $Th_{MER}$ correspond to a zone where uncertainty about the necessity to carry out the Handoff still remains):

- if $MER > Th_{MER}$
  $\rightarrow$ Jump to Measurement and data collection (State 1);
- if $MER < Th_{MER}$ and “UMTS cell is NOT border cell”
  $\rightarrow$ Jump to Measurement and data collection (State 1);
- if $MER < Th_{MER}$
  $\rightarrow$ Jump to MER Prediction (State 3).

Like in the previous State, if user is not in a border cell and measured MER is greater than a critical threshold ($Th_{CR}$) but below an optimal value ($Th_{MER}$), then further measurements are required to evaluate the actual need for an Handoff.

State 3. MER Prediction.

The predictor module uses the content of the register, i.e. the most recent k MER samples, and predicts the next MER value, $MER^{(k+1)}$. Then, it compares such a value with the $Th_{HO}$ threshold (it is the MER value below which the Handoff Execution is triggered) according to the following rules:

- if $MER^{(k+1)} > Th_{HO}$
  $\rightarrow$ Jump to Measurement and data collection (State 1);
- if $MER^{(k+1)} < Th_{HO}$
  $\rightarrow$ Jump to Handoff Execution (State 4).


Instead of performing RSSI measurements on both the serving cell and all adjacent cells, according to the usual procedure [6], [7], we propose to build the Candidate Signals List by means of the received DVB-H Handoff-Related Information. Channels, both in the Neighboring List and in
NIT, are sorted and included in a high priority queue; channels in the Fake Signals List are discarded; the remaining ones (i.e. those found in NIT but not in the Neighboring List) are placed in a low priority queue. A terminal will carry out RSSI measurements only on the channels (of adjacent DVB-H cells) in the high priority list, by starting from the one with the highest measured RSSI. Terminals will scan the channels in the low priority list just if (unlikely event) previous RSSI measurements are below the acceptable threshold. It is straightforward that, the lower the number of frequencies in the high priority list, the faster will be the handover execution and the lower the power consumption. A reduction in the number of adjacent cells is strictly connected to the ratio of UMTS cell coverage vs. DVB-H cell coverage (named $K_{\text{UMTS/DVB-H}}$). The smaller this ratio, the lowest the number of adjacent DVB-H cell (adjacent to the UMTS border cell). This translates into faster handover and shortest DVB-H front-end activation period.

V. EVALUATION CAMPAIGN

An exhaustive evaluation campaign is conducted to assess the performance of our algorithm. The evaluation is based on real MER data, measured during field test campaigns by means of HW and SW equipments and tools made available by Aircom International. Based on our previous work [4], we have used different set of threshold values ($\text{Th}_{\text{MER}}$, $\text{Th}_{\text{HO}}$, $\text{Th}_{\text{CR}}$); to make results independent of context and mobility conditions, we focused our attention on two types of users: pedestrian (in the middle, and in border DVB-H cell) and vehicular (two different routes inside DVB-H network).

First objective has been the tuning of the predictor module, in the view of best dimensioning its registers and minimizing the prediction errors. To this aim, we considered the output of several MER measurement campaigns. Tests demonstrated that a register size of 13 is able to keep the prediction error at extremely low values. $\text{Th}_{\text{CR}}$ represents the value of MER under which it is necessary to trigger the Handoff Decision procedure. To evaluate this threshold we compared the MER trend with that of one of the Carrier-to-Interference Ratio (C/I) and we observed that a critical value of MER is approximately 11.5 dB. Besides, a safety margin of 0.5 dB is added so to consider possible errors introduced by the predictor module. Obviously, $\text{Th}_{\text{CR}}$ value is the same for the three threshold sets. The more appropriate values of $\text{Th}_{\text{MER}}$ and $\text{Th}_{\text{HO}}$ thresholds have been determined by taking into account two conditions: (i) the gap between two thresholds must be greater than 0.5 dB to take into account the prediction error; (ii) a MER value of 16 dB already corresponds to an acceptable quality above which defining any further threshold it unnecessary to. Actually, we tested several thresholds sets; in Table 1 only those which showed the best performance are reported.

![Table 1: Threshold Sets](image)

Moreover, in order to evaluate the performance improvements deriving from the DVB-H related information transmitted by the cellular network, we defined some simple metrics: (i) $K_{\text{UMTS/DVB-H}}$, i.e. the adjacent reduction factor related to the ratio of UMTS and DVB-H coverage area; (ii) percentage of reduction in handoff execution time ($\text{Saved}_{\text{HO\_Time}}$); (iii) the percentage of energy saved ($\text{Saved}_{\text{HO\_Energy}}$) during handoff execution; (iv) the percentage of energy saved due to avoided handoff executions when using MER as a quality indicator ($\text{Saved}_{\text{HO\_Energy\_Avoided}}$). In [7], time spent for Handoff execution ($\text{HO\_time}$) is:

$$\text{HO\_time} = N_{\text{RSSI}} \cdot t_{\text{RSSI}} + N_{\text{SYNCH}} \cdot t_{\text{SYNCH}}$$

where $N_{\text{RSSI}}$ and $N_{\text{SYNCH}}$ are, respectively, the number of RSSI measurement and synchronization trials (due to fake signals), while $t_{\text{RSSI}}$ and $t_{\text{SYNCH}}$ are the time durations needed for RSSI measurement execution and synchronization during the Off-Time (see [7] for details). By using UMTS-Assisted Handoff, the percentage of Saved HO Time (i.e. the ratio of UMTS-assisted handoff and standard handoff duration) is:

$$\text{Saved}_{\text{HO\_time}} = \left(1 - \frac{K_{\text{UMTS/DVB-H}} \cdot N_{\text{RSSI}} \cdot t_{\text{RSSI}} + N_{\text{SYNCH}} \cdot t_{\text{SYNCH}}}{N_{\text{RSSI}} \cdot t_{\text{RSSI}} + N_{\text{SYNCH}} \cdot t_{\text{SYNCH}}}\right) \cdot 100$$

The energy consumption during standard handover execution is directly related to the number of measurements and synchronizations. It’s worth pointing out that synchronization is a more consuming process than RF measurement, as the demodulator must be switched on together with the front-end [8],[9]. Let the energy consumption be:

$$E_{\text{normal}} = p_{\text{FE}} \cdot N_{\text{RSSI}} + p_{\text{FE\_DEM}} \cdot N_{\text{SYNCH}}$$

where $p_{\text{FE}}$ is a factor taking into account the energy spent during RF measurement, and $p_{\text{FE\_DEM}}$ is related to the synchronization activities. This information can be acquired from the manufacturer/datasheet of DVB-H receiver module embedded into dual mode terminals [8],[9]. The amount of energy consumed by the proposed technique is given by:

$$E_{\text{speed}} = p_{\text{FE}} \cdot K_{\text{UMTS/DVB-H}} \cdot N_{\text{RSSI}} + p_{\text{FE\_DEM}}$$

By defining $p_{\text{FE\_DEM}}/p_{\text{FE}}$ as a proportionality factor $p_{\text{R}}$, the percentage of energy saved ($\text{Saved}_{\text{HO\_Energy}}$) during handoff execution can be written as:

$$\text{Saved}_{\text{HO\_Energy}} = \left(1 - \frac{K_{\text{UMTS/DVB-H}} \cdot N_{\text{RSSI}} + p_{\text{R}} \cdot N_{\text{SYNCH}}}{N_{\text{RSSI}} + p_{\text{R}} \cdot N_{\text{SYNCH}}}\right) \cdot 100$$

Energy savings due to avoided handoff execution when using MER as a quality indicator, could be expressed as [3],[4]:

$$\text{Saved}_{\text{HO\_Energy\_Avoided}} = \frac{N_{\text{RSSI\_based}} - N_{\text{MER\_based}}}{N_{\text{RSSI\_based}}} \cdot 100$$

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It is derived from the difference between the number of handoff executions according to the standard ($N_{\text{RRI-based}}$) and the number of handoff executions (State 4) foreseen by the proposed approach ($N_{\text{MER-based}}$). By focusing on energy saving due to avoided handoff execution (Figure 1), our technique allows at least a 45% energy saving in the worst case (pedestrian users at the border cells), while users in the middle of DVB-H cells make no handover (energy saved 100%).

Reduction in the handoff execution time (Figure 2) and energy saving during Handoff execution (Figure 3) are evaluated by choosing $p_R=2.5$ [9] and an average number of synchronization trials $N_{\text{SYNC}}=5$ [7]. By looking at the percentage of reduction in the handoff execution time (Figure 2), as expected, the coverage ratio $K_{\text{UMTS/DVB-H}}$ (K in Figure 2) between UMTS and DVB-H cells directly translates into a reduced number of candidate channels to be measured.

To validate the obtained results we need to assess whether the use of our technique increases the dropping probability in the DVB-H system or not. We verified that each time the terminal actually needs a handoff, it enters the State 4, thus executing RSSI measurement according to the RSSI-based handoff procedure. This allows to state that, in all conducted test campaigns, dropping probability never appreciably increases with respect to the case of RSSI-based handoff procedure.

VI. CONCLUSIONS

This paper has shown the results of an early study aiming at defining new mechanisms for the management of handoff procedures in DVB-H. MER quality index proved to be useful to enhance the standard RSSI-based Handoff measurement procedure. We also demonstrated that the integration of DVB-H and UMTS networks and the transmission of DVB-H related information in UMTS cells may bring relevant advantages in terms of faster HO executions and reduced energy consumption.

REFERENCES

[5] “GSM Cell Broadcast Services description”, GSM 02.03 v5.3.2 Annex A1.3.4 section 4. www.3gpp.org