Practical implementation of Mobile TV delivery in cooperative LTE/DVB networks

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***Abstract*—We propose in this paper, some practical algorithms to deliver Mobile TV in a hybrid network where coexist both LTE and DVB-NGH technologies and two types of demanded video qualities: a basic single definition and another high definition. Those algorithms aim to manage the continuous reception of Mobile TV by using both infrastructures and taking decisions of TV scheduling on those operators. Two decisions policies are explored: one based on instantaneous actions and a second based on predictive actions. Results shows that the latter, which uses the Kalman filter, decreases the ping-pong between the HD reception delivered by LTE and the SD one offered by DVB-NGH, if compared to the former policy.**

I. Introduction

Both 3rd Generation Partnership Project (3GPP) and Digital Video Broadcasting (DVB) organisations aim, nowadays, to offer Mobile TV services. The former intends to deliver it by means of the Long Term Evolution (LTE) technology [1] thanks to its broadcast capability introduced with Enhanced-Multimedia Broadcast Multicast Services (e-MBMS) feature [2]. On the other side, DVB targets this service with its DVB-Next Generation Handheld (DVB-NGH) technology [3], which is the mobile extension of the second generation terrestrial transmission system (DVB-T2) [4].

The performance of Mobile TV delivery has been for quite some time studied by researchers: some studied the LTE solution [5], other considered, however, the DVB network [6], and finally some papers considered a hybrid system where coexist both LTE and DVB-NGH operators and cooperate for an efficient delivery of Mobile TV [7][8]

Authors in [5], studying the performance of a LTE network delivering Mobile TV service, assessed the amount of resources to be dedicated to deliver TV services without affecting the Quality of Services (QoS) of voice and data flows. Authors in [6], considering the DVB-T2 network, presented a procedure to test the mobile reception performance in this network. We, however, considered in our previous works [7] and [8] a hybrid system where LTE and DVB-NGH operators cooperate to offer TV services for different mobile terminals requirements (high and single definition, noted by HD and SD respectively). In [7] the DVB and LTE operators partition the service area into two concentric regions. DVB-NGH offers the overall TV service (HD and SD) in the inner region and LTE delivers the same service in the outer region. Results show that this configuration will decrease the overall energy consumption for a green mobile TV delivery. We adopted in [8] a different variation of the cooperative network configuration, where DVB-NGH serves both HD and SD users in the inner region and only the basic SD in the outer region. The HD service is delivered by LTE in this latter region. This configuration will decrease further the required LTE infrastructure and thus the energy consumption.

In those latter papers we dedicate a given LTE bandwidth for Mobile TV services, in order to guarantee its continuous delivery. But the presence of another operator, motivates us to investigate in this paper a solution, where the LTE mobile TV services share bandwidth with its unicast (i.e. voice and data) services (in order to decrease the need of expensive bandwidth resources). If LTE doesn't have the sufficient resources to deliver the HD service, this latter will not be scheduled and the HD user will receive, instead, the "always on" basic SD service from DVB network.

This scheduling management may suffer from an annoying ping-pong behaviour between the operators, due to the dynamicity of the available LTE resources. We introduce so, a predictive algorithm based on Kalman filter [9] for a better scheduling decisions and thus an enhanced delivery solution.

The remainder of this paper is organized as follows, in Section II we describe the network. In Section III we explore two decision policies to schedule the HD Mobile TV on LTE: the first is based on instantaneous observations of available resources and the second is based on futurist available resources obtained by Kalamn prediction. The numerical results and the performance of both strategies are illustrated in section IV. We,eventually, conclude our work in section V

II. Network Description

We consider a service area of R [Km], where coexist both DVB and LTE operators (fig. 1) and two types of terminals: one requiring SD services and the other HD ones.

The DVB network is chosen to deliver the basic SD services in the whole region and the LTE one to serve in the same region the HD service. In fact the SD is the minimum reception quality that must be received all the time and thus it should be delivered by the most robust system which is the DVB-NGH.

The capacity and coverage dimensioning of this "always on" DVB-NGH network are described in [8] and [7] respectively.

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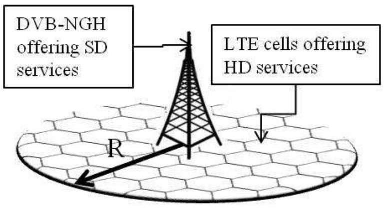

Fig. 1. Service Area

The LTE network is, however, considered in this paper to be shared between unicast and TV services. So the available resources, known as physical resource blocks (PRB), must be partitioned between them. A PRB is a chunk of 12 narrowband sub-carriers of 15 KHz each and it represents the smallest amount of resources a served connection can get. The total number of those PRBs, noted by N_{RB}^{max}, depends on the LTE bandwidth [10]. However, the offered throughput by a single PRB depends on the transmission mode.

Voice calls are real-time demands served by Point to Point (P2P) unicast connections. The average throughput offered by a PRB in this unicast mode, which we denote by $\overline{d_{RB}}$, is calculated in [11] for a given LTE cell radius r. As a result, a single voice call of bitrate d_v will be allocated an average number of PRB, n_{RB}^{v}, given by:

$$n_{RB}^{v} = \frac{d_v}{\overline{d_{RB}}} \tag{1}$$

Mobile TV demands are, however, served by e-MBMS the broadcast solution of LTE in a Single Frequency Network (SFN) mode, where cells are synchronised to deliver the same content at each instant. The PRB average throughput in this latter case, denoted by $\overline{d_{RB}^{SFN}}$, is calculated in [12]. The number of PRB demanded by a TV connection of bitrate d_{TV} is thus given by:

$$n_{RB}^{TV} = \frac{d_{TV}}{\overline{d_{RB}^{SFN}}} \tag{2}$$

Voice calls are the primary services and are served first, Mobile TV services will use the remaining bandwidth. We note here, that the TV channels do not have the same transmission priority, their popularities follow a Zipf distribution[13]. So, given a number of voice calls n_v in the network, the LTE will serve the $n_{TV}(n_v)$ most priority TV channels. In other words, $n_{TV}(n_v)$ is the maximal number of TV channels that can be served, when there is n_v voice connections in the network and it verifies the following equation:

$$\lceil n_v \cdot n_{RB}^{v} + n_{TV}(n_v) \cdot n_{RB}^{TV} \rceil = N_{RB}^{max} \tag{3}$$

where N_{RB}^{max} is the maximal number of PRB available in the considered LTE network [10], n_v is the number of served voice calls in the cell, n_{RB}^{v} (eq. 1) and n_{RB}^{TV} (eq.2) are the amounts of PRB allocated to a single voice calls and TV channel respectively.

The unicast/TV shared LTE network decreases the need for expensive bandwidth at the expense of the continuous TV delivery. In fact it can not always guarantee the sufficient resources to deliver this latter service. So, we propose in the next section some practical algorithms for a continuous Mobile TV delivery taking advantage of the existence of both LTE and DVB-NGH operators.

III. Mobile TV delivery

The main idea of our proposed algorithms, is to determine how the Mobile TV is scheduled on the operators. The basic SD TV service is always scheduled on the DVB network and can be received by the user at anytime. The HD one, however, should be scheduled on LTE according to two decision policies described in the following:

A. Instantaneous Decisions

We describe in this subsection the instantaneous decision policy. The LTE network observes the network state at each time step τ, and decides to schedule a TV channel TV_k of priority k if there is sufficient remained resources at this observed instant. This strategy is described in algorithm A:

Algorithm A:

1) observe the number of served voice calls n_v each τ [s]
2) if $\lceil n_v \cdot n_{RB}^{v} + k \cdot n_{RB}^{TV} \rceil > N_{RB}^{max}$ is verified, the considered TV_k HD service is not scheduled on LTE but the user receives the basic TV service (SD) from the "always on" DVB-NGH instead of waiting passively the LTE to regain its transmission capability
3) reobserve the number of served voice calls n_v each τ [s]
4) if $\lceil n_v \cdot n_{RB}^{v} + k \cdot n_{RB}^{TV} \rceil <= N_{RB}^{max}$ the HD channel is rescheduled on LTE and received by the user and we return to step 1 else return to step 3

We note here that voice calls follow a Poisson arrival distribution with parameter λ_v and an exponential service time distribution with parameter μ_v, and thus the network state might change each $\tau = \frac{1}{\lambda_v + n_v \mu_v}$. So, the main disadvantage of this decision solution is the frequent ping-pongs between LTE-DVB receptions that might occur in a very dynamic network. Or even the no needed reception switches due to a small duration change in the scheduling conditions (step 2 and 3 in algorithm A). We were thus motivated to consider a predictive TV channel scheduling management as described in the next section.

B. Predictive Decisions

Usually the voice traffic intensity does not change as instantaneously as the exact number of voice calls. It lasts for a non negligible period of time Δ_t. We note that these services have a regular pattern shape in a cellular network. It consists of low load period during night and higher load period during day.

On the other side, voice calls follows an Erlang distribution. So, the mean of the number of those calls is approximately equal to the distribution parameter $\frac{\lambda_v}{\mu_v}$ which is the voice traffic intensity. This means that the average number of voice calls doesn't change frequently and it is more beneficial if we take the TV scheduling decisions based on it.

As we are taking decision based on a near-term future and not instantaneously (according to the network state in the next period of time Δ_t), we must predict at the beginning of each time step t the average number of voice calls in the next interval $[t, t + \Delta_t]$. We choose the Kalman filter [9][14] for this prediction.

1) Kalman filter description: The appealing advantage of Kalman filter is its ability to estimate the future state based only on the last predicted state. This leads to a simple and light implementation on the network softwares.

This recursive filter consists of a prediction phase and another correction phase:

- *Prediction Phase:* It gives, at the current time step t, the "a priori" estimation of the average number of voice calls that will be present in the network during the time interval $a = [t, t + \Delta_t]$. It is denoted by $\overline{n_v}^*(a)$ and obtained based on the already predicted average that was present during the previous interval $b = [t - \Delta_t, t]$. This latter, denoted by $\overline{n_v}(b)$, is called the "a posteriori" estimation at the interval b and it is the output of the Kalman filter in the considered interval b after the correction phase (this phase is introduced latter).
  $\overline{n_v}^*(a)$ is given by:
  $$\overline{n_v}^*(a) = f(\overline{n_v}(a - \Delta_t)) \tag{4}$$
  where f is the model function that describes the real evolution of the system and relates thus the value of the average number of voice calls in interval a, $\overline{n_v}^r(a)$, to its value in interval b with a given model error e_a. In other word, f gives the analytical evolution of the system as follows:
  $$\overline{n_v}^r(a) = f(\overline{n_v}^r(a - \Delta_t)) + e_a \tag{5}$$
- *Correction Phase:* It updates, at the end of the time interval a (at the instant $t+\Delta_t$) the "a priori" estimation $\overline{n_v}^*(a)$ and refines it with live measurements of the average number of voice calls done during the interval a. The output of this phase is called the "a posteriori" estimation and noted by $\overline{n_v}(a)$
  $$\overline{n_v}(a) = \overline{n_v}^*(a) + K_g(a) \cdot (\overline{n_v}^m(a) - \overline{n_v}^*(a)) \tag{6}$$
  where $\overline{n_v}^m(a)$ is the average number of voice calls present in the interval a and obtained by direct measurements, $\overline{n_v}^*(a)$ is the "a priori" estimation of this average obtained in the prediction phase (eq. 4) and finally $K_g(a)$ is the Kalman filter gain at the interval time a, and it is obtained by the later equation:
  $$K_g(a) = \frac{P(a)}{(P(a) + R)} \tag{7}$$
  where R is the variance of measurement system error and $P(a)$ is the variance of the "a posteriori" estimation error: $P(a) = \mathrm{Var}(\overline{n_v}^r(a) - \overline{n_v}(a))$. But we can not calculate it in this way, because we do not have the history (over the time) of the "a posteriori" estimation $\overline{n_v}(a)$. However, it can be obtained recursively by:
  $$P(a) = P^*(a - \Delta_t) + Q \tag{8}$$
  We note that $P^*(b) = \mathrm{Var}(\overline{n_v}^r(b) - \overline{n_v}^*(b))$ is the variance of the "a priori" estimation error in the interval b. Once again we can not calculate it from its definition because of the lack of the history of the "a priori" estimation, $\overline{n_v}^*(b)$. It is, however, given by the equation:
  $$P^*(b) = (1 - K_g(b)) \cdot P(b) \tag{9}$$

2) Implementation of Kalman filter in our network: We will use the same model described in [15] to determine the Kalman filter parameters, which are the model evolution function f, the variance of model error Q and that of measurement error R. (Let's note that Q and R can be usually obtained by simulations and curve fitting but since we don't have the exact model evaluation function we will calculate them based on a history of voice call states).

We consider an observed period of time $T = 24$ hours of a week day. The observed period is divided into $N_I = \frac{T}{\Delta_t}$ intervals, with Δ_t is the period of time where the average number of voice calls is constant. This average increases or decreases during the next interval and thus the exact system evolution is:

$$\overline{n_v}^r(a) = \overline{n_v}^r(a - \Delta_t) + \delta^r(a) \tag{10}$$

This exact model (especially $\delta^r(a)$) can not be previously known at each day. However we can find an estimated model based on the history of the system evolution over M days. This latter represents the average number of voice calls in the M week days in each interval $a \in \{1, .., N_I\}$ (the more we have history informations about those weeks days the more the prediction is accurate). As depicted in [15], the model evolution (eq. 5) (function f) is thus estimated and defined as follows:

$$\overline{n_v}^e(a) = \overline{n_v}^e(a - \Delta_t) + \delta(a) + e_a \tag{11}$$

where $\overline{n_v}^e(a)$ is the network state obtained from the analytical model function and $\delta(a)$ is the main parameter of the model that relates the value at the next interval to this value at the previous interval. It represents the traffic trend and is obtained by averaging the history traffic trends over the considered M days:

$$\delta(a) = \sum_{i=1}^{M} \frac{\overline{n_v}_i^r(a) - \overline{n_v}_i^r(a - \Delta_t)}{M} \tag{12}$$

with $\overline{n_v}_i^r(b)$ is the real value of the average number of voice calls in the interval b at day i taken from the set of considered history.

The model error e_a is due to the use of the estimated trend $\delta(a)$ instead of the real $\delta_i^r(a)$ in the estimation of the day i traffic evolution. So, once again e_a is the model error, $\delta_i^r(a) - \delta(a)$ in each interval a of the day i, averaged over the taken M days and the Kalman filter parameter Q is the variance of this model error in the N_I intervals.

The variance of the measurements error R could be considered as equal to 0, because the LTE system can know at each measurement time step the exact number of served voice calls, simply by observing its consumed resources.

Finally, given the input parameters $\delta(a)$, Q and R, we apply the later Algorithm B while considering the TV channel of priority k:

Algorithm B:

1) Begin with time step t=0
2) We initialize the variance of the "a posteriori" estimation error in the first observed interval (eq:8): $P([0, \Delta_t]) = 0$
3) We initialize the first value of the "a posteriori" estimation $\overline{n_v}([0, \Delta_t])$ by the mean number of voice calls in the interval $[0, \Delta_t]$, of each day in the history set averaged over the total M days.
4) We measure the present number of voice calls in the network and memorize it.
5) We increment t by the measurement time step τ: $t_{new} = t + \tau$, if $t_{new} = 24$ [hours] stop, else move forward to the next step.
6) If $t_{new} = t + \Delta_t$ (Δ_t is the interval in which the average number of voice calls doesn't change), We get the "a priori" prediction of the average number of voice calls in the next interval $a = [t_{new}, t_{new} + \Delta_t]$,
$$\overline{n_v}^*(a) = \overline{n_v}(a - \Delta_t) + \delta(a)$$
where $\delta(a)$ is given in eq. (12). We move, then, to step 7.
If however $t_{new} < t + \Delta_t$, we update t by t_{new} and return to step 4.
7) If $\lceil \overline{n_v}^*(a) \cdot n_{RB}^v + k \cdot n_{RB}^{TV} \rceil > N_{RB}^{max}$ is verified the HD TV channels TV_k is not scheduled on LTE.
8) Average all the memorized measurements in the interval $[t, t + \Delta]$
9) Update the "a priori" estimation by this average to get the "a posteriori" estimation by applying equations (9),(8),(7),(6) in this order and return to step 4.

IV. Numerical Results

We consider a service region of 7 [Km], where coexists DVB and LTE operators. DVB is dimensioned to offer 7 SD TV channels of 250 [Kbps] ([8]). The LTE cell is of radius $r = 5$[Km] and has a bandwidth of 5 [MHz] ($N_R B^{max} = 25$). LTE serves both voice calls with the single call average throughput $d_v = 50$ [Kbps] and 7 HD TV channels of 512 Kbps each. The average throughput offered by a single PRB to unicast connection is of 237 (results of [11]) and that in the SFN mode is of 260 [Kbps] (numerical results of [12]).

We take the example of the least priority TV channel TV_7, this channel can be served by LTE for a given number of voice calls less than 56.

We simulate an Erlang voice traffic for a period of time of 24 hours. We know that the traffic intensity changes each $\Delta_t = 30$ minutes. We present in Figure 2, the switch behaviour between LTE and DVB-NGH based on instantaneous decisions

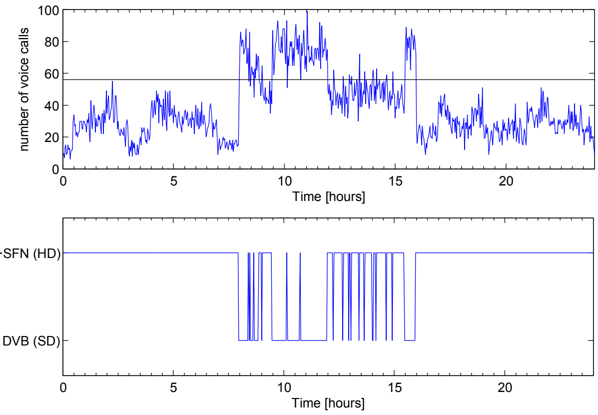

Fig. 2. The switch behaviour between LTE and DVB-NGH based on instantaneous decisions

It is clear that this decision policy will lead to frequent ping-pong of TV reception between the operators due to a brief violation of the threshold voice number $n_v = 56$ (eq. 3). Those latter are represented as ascendant and descendant dirac impulsions in the figure 2. If the current delivering operator knew that these changes will not last for a longer duration, it might not demand a TV rescheduling on the other operator.

We present, however, in figure 3, the behaviour based on Kalman predictive decisions compared to that based on instantaneous decisions. We notice that the number of the reception ping-pongs is decreased, the system doesn't take, any more, the brief switch tendency into account. However, in this solution HD user will visualize, some brief interruptions in the service (periode 12 h - 15:30). This inconvenient can be eliminated by introducing buffers at the receiver side, which can absorb those brief interruptions.

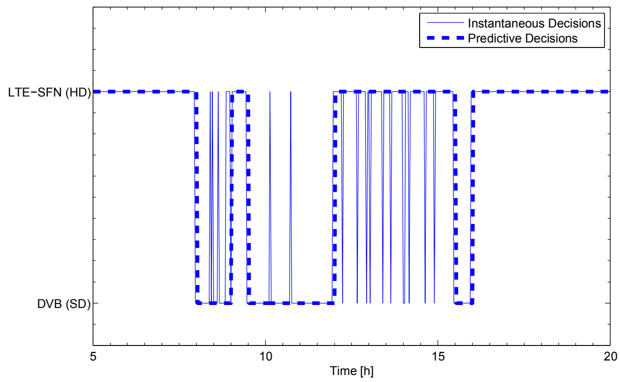

Fig. 3. The switch behaviour between LTE and DVB-NGH based on predictive decisions

V. Conclusion

We investigated in this paper two implementation scenarios of Mobile TV in a cooperative LTE/DVB-NGH network, where LTE relies on DVB-NGH if it lacks of bandwidth resources. We consider a network where the basic SD is always scheduled on DVB-NGH, and the HD services are scheduled on LTE, or not, according to some decision policies. If the TV channel is not scheduled on LTE, the HD users, will receive the basic quality service from DVB until LTE regains its transmission capability.

We investigated two scheduling decision policies, one based on the instantaneous measure of the LTE network state, and the other on the near-term predicted state. Results show that the second implementation is better since it decreases the scheduling ping-pong between the operators, but users will suffer from brief interruptions. We will consider in our future works the introduction of buffers at the receiver side to eliminate these service cut-off.

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