# Optimal Design of Superframe Pattern for DVB-RCS Return Link

Ki-Dong Lee, Yong-Hoon Cho, Seung Joon Lee, and Ho-Jin Lee

*ABSTRACT¾ We developed a method for optimal superframe design in the multi-frequency time division multiple access (MF-TDMA) return-link of a satellite multimedia interactive network called a digital video broadcasting return channel over satellite (DVB-RCS) sub-network. To find the optimal superframe pattern with the maximum data throughput, we formulated the design problem as a non-linear combinatorial optimization problem. We also devised the proposed simple method so that it would have field applicability for improving radio resource utilization in the MF-TDMA return link.*

## I. INTRODUCTION

The digital video broadcasting (DVB) return channel over satellite (RCS) system is a geostationary earth orbit (GEO) satellite interactive network providing multimedia, including Internet traffic service [1]-[2]. Worldwide companies and industries are developing broadband interactive satellite systems. Recently, their commercial availability was announced [3]. It is expected that the network access demand will increase and, therefore, strategies to achieve high utilization of the limited available radio resources are of great importance to accommodate the increase of demand at the lowest possible cost.

For the return link in DVB-RCS systems, since there is neither a broadcasting effect as in the forward link nor reuse efficiency as in cellular systems, achieving high capacity with limited radio resources is an important focus of investigation. The European Telecommunications Standards Institute's DVB-RCS standard [2] calls for a return link using a multi-frequency time division multiple access (MF-TDMA) scheme. Thus, we were motivated to find the optimal superframe pattern providing maximum data throughput in an MF-TDMA scheme for the DVB-RCS return link. The proposed method could be applied to superframe design problems in the practical development of an interactive satellite multimedia network.

## II. OPTIMAL SUPERFRAME DESIGN

### 1. Frequency Utilization Model of the Return Link

In this letter, the total available resource is defined as a specific region (whether finite or infinite) in the time-frequency plane $(\mu\text{s} \cdot \text{MHz})$. We consider the total bandwidth resource $W$ in our resource utilization model of the DVB-RCS return link. The time-frequency resource is partitioned into superframes, a superframe into frames, and a frame into timeslots (Fig. 1). In MF-TDMA for DVB-RCS, transmission is organized in superframes. The time-frequency plane of the region $(-\infty, \infty) \times [-W/2, W/2]$ is divided into superframes $[mT_{sf}, (m+1)T_{sf}] \times [-W/2 + (n-1)W_{sf}, -W/2 + nW_{sf}]$ for $m \in Z$ and $n = 1, \cdots, y_{sf}$. Each superframe $[mT_{sf}, (m+1)T_{sf}] \times [nW_{sf}, (n+1)W_{sf}]$ is partitioned into time-frequency frames $[mT_{sf} + (k-1)T_f, mT_{sf} + kT_f] \times [nW_{sf} + (l-1)W_f, nW_{sf} + lW_f]$ for $k = 1, \cdots, x_f$ and $l = 1, \cdots, y_f$. The total number of frames in a superframe is $x_f \cdot y_f$. Each frame $[mT_f, (m+1)T_f] \times [nW_f, (n+1)W_f]$ is partitioned into time-frequency timeslot streams $[mT_f, (m+1)T_f] \times [nW_f + (l-1)W_t, nW_f + lW_t]$ for $l = 1, \cdots, y_t$. A timeslot stream $[mT_f, (m+1)T_f] \times [nW_t, (n+1)W_t]$ consists of concatenated timeslots in a predetermined order as follows: one

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CSC (common signaling channel) timeslot of duration $T_{\mathrm{csc}}$, one ACQ (acquisition) timeslot of duration $T_{acq}$, $x_{sync}$ SYNC (synchronization) timeslots with a total duration $x_{sync}T_{sync}$, and $x_{trf}$ TRF (traffic) timeslots with a total duration $x_{trf}T_{trf}$ where we have $T_f = T_{\mathrm{csc}} + T_{acq} + x_{sync}T_{sync} + x_{trf}T_{trf}$. The total number of TRF timeslots per frame is $x_{trf} \cdot y_t$. Each timeslot contains a burst surrounded by guard time $G_T$ and guard band $G_W$. A CSC burst consists of a 256 symbol preamble and a 150 symbol encoded burst, an ACQ burst of a 256 symbol preamble, a SYNC burst of a 256 symbol preamble and a 182 symbol encoded burst, and a TRF burst of a 48 symbol preamble and a $[8(53x_{cell}+16)+6]$ symbol encoded burst, where $x_{cell}$ denotes the number of ATM cells per TRF timeslot, and Reed Solomon outer coding and Convolutional inner coding are used [2].

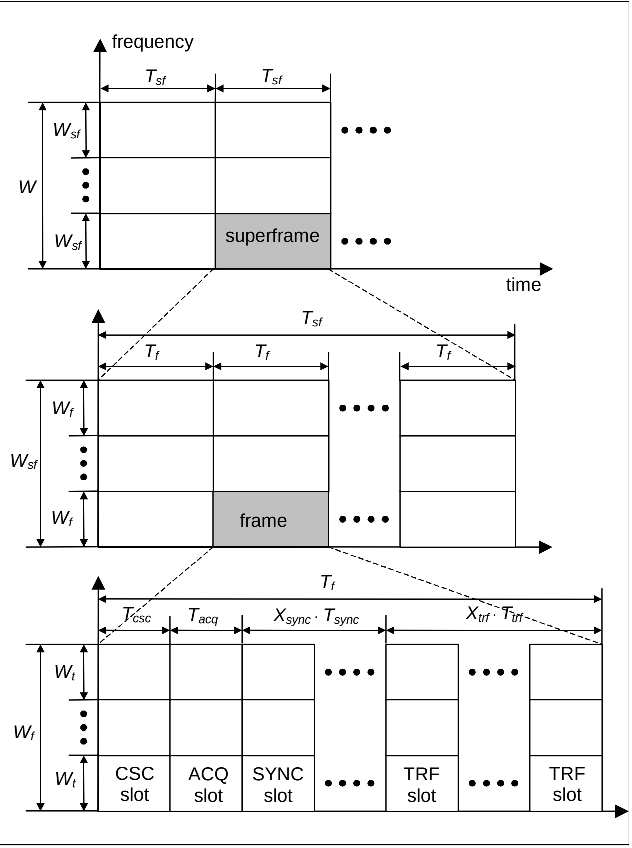

Fig. 1. Superframe structure in the time-frequency plane.

## 2. Problem Formulation

Our major focus was on finding a superframe pattern with the maximum net information rate (NIR) of users. Normalizing the NIR by the bandwidth and the duration of a superframe yields an objective written as

$$R(\mathbf{x},\mathbf{y}) = \frac{y_f \cdot x_f \cdot y_t \cdot x_{trf} \cdot x_{cell}}{W_{sf} \cdot T_{sf}} \cdot c \tag{1}$$

where $\mathbf{x} = (x_f, x_{sync}, x_{trf}, x_{cell})$, $\mathbf{y} = (y_{sf}, y_f, y_t)$, and $c$ is a constant denoting the number of user information bits per ATM cell.

$$(\mathbf{P}) \qquad \max_{\{\mathbf{x},\mathbf{y}\}} R(\mathbf{x},\mathbf{y})$$

subject to

$$(W_t - G_W)(T_{\mathrm{csc}} - G_T) \ge 1.35(256+150) \tag{2}$$

$$(W_t - G_W)(T_{acq} - G_T) \ge 1.35 \times 256 \tag{3}$$

$$(W_t - G_W)(T_{sync} - G_T) \ge 1.35(256+182) \tag{4}$$

$$(W_t - G_W)(T_{trf} - G_T) \ge 1.35(48 + 8(53x_{cell}+16)+6) \tag{5}$$

$$y_{sf} \le W / W_{sf} \tag{6}$$

$$y_f \le W_{sf} / W_f \tag{7}$$

$$y_t \le W_f / W_t \tag{8}$$

$$T_{sf} \le U_D \tag{9}$$

$$x_f \le T_{sf} / T_f \tag{10}$$

$$T_f = T_{\mathrm{csc}} + T_{acq} + x_{sync}T_{sync} + x_{trf}T_{trf} \tag{11}$$

$$x_{trf} \cdot y_t \le 2048 \tag{12}$$

$$x_f \cdot y_f \le 32 \tag{13}$$

$$x_f \cdot y_f \cdot x_{sync} \cdot y_t \ge c_R \tag{14}$$

$$x_{cell} = 1, 2, or\ 4$$

$$x_f, x_{sync}, x_{trf}, y_{sf}, y_f, y_t : \text{ positive integers.}$$

We must consider the symbol rate $S$ and the roll-off factor $\alpha$ in determining the bandwidth of a timeslot $W_t$. With quadrature phase shift keying (QPSK), the bandwidth of a burst $(W_t - G_W)$ should be equal to $(1+\alpha)S$ (MHz), and it takes $n/s$ μs to transmit $n$ symbols. The $n$ symbols can be transmitted with a time-frequency resource with a size of $(1+\alpha)S \cdot n/s = (1+\alpha)n$ (μs · MHz), which is not dependent on $S$. For example, with a symbol rate $S' = m \cdot S$, the same time-frequency resource is sufficient, the required bandwidth is $m(1+\alpha)S$ (MHz), and the transmission time will be $n/(ms)$ μs. However, the capacity is dependent on the bandwidth $(W_t - G_W)$ and the duration $(T_{timeslot-type} - G_T)$, although the time-frequency resource is the same. With $\alpha = 0.35$ as in [2], it is $1.35n$ as shown in (2)-(5).

Constraints (6)-(8) show that the numbers of superframes, frames, and carriers are upper-bounded in the frequency domain. Constraints (9) and (10) show that superframe duration and the number of frames are upper-bounded in the time domain. Constraint (11) shows that a frame has $x_{sync}$ SYNC timeslots and $x_{trf}$ TRF timeslots including one CSC timeslot and one ACQ timeslot in the time domain. Eqs. (12) and (13) show that a frame has at most 2048 TRF timeslots and a superframe has at most 32 frames. In (14), $c_R$ is the target capacity for the number of simultaneously active RCS terminals (RCSTs). If there are a lot of short payloads, such as web browsing requests, the optimal value of $x_{cell}$ might be less than 4 in reality. According to the payload (traffic) characteristics, variable $x_{cell}$ could be restricted by an additional constraint. However, an RCST is generally a group terminal where payloads are merged before transmission in DVB-RCS.

## 3. Solution Method and Numerical Examples

The optimal design of the frame pattern is known as an NP-Complete problem [4], [5]. The Lagrangean relaxation algorithm [6] and a column generation technique [7] are widely used for finding the near-/global-optimum of NP-Complete problems. Even though the objective is not linear, an optimization problem could be simply solved by non-linear convex programming techniques if the objective and feasible set are all convex [8].The objective and constraints of our problem $(\mathbf{P})$ are not linear, and the feasible set cannot be guaranteed to be convex. Thus, solving $(\mathbf{P})$ is more difficult than solving a general Knapsack-type problem with a linear objective and constraints. We can easily show that $(\mathbf{P})$ can be reduced to a pure integer programming (IP) problem that can be solved by a simple algorithm.

Some important properties are analyzed for a simple and exact solution algorithm. At the optimum, equality holds in (6), (7), (8), and (10). Using (6), (7), and (8), we can express real variables $W_{sf}$, $W_f$, and $W_t$ by $W$, $y_{sf}$, $y_f$, and $y_t$. Using these results with (2)-(5), and (10), we can express (9) and (11) as a pure fractional integer constraint. Thus, $(\mathbf{P})$ can be reduced to a pure IP problem.

Consider a sub-problem where some of the decision variables are fixed. For any given $(y_{sf}, y_f, y_t)$ and $x_f$ in the feasible set, $(x_{trf}, x_{sync}, x_{cell}) = \left(\lfloor 2048/y_t \rfloor, \lceil c_R/(x_f y_f y_t) \rceil, 4\right)$ is the best. With the given $(y_{sf}, y_f, y_t)$ and the best $(x_{trf}, x_{sync})$, $T_f$ is determined by (2)-(5), and (11), with the result that $x_f = \lfloor U_D/T_f \rfloor$ is the best. If there is at least one decision variable that violates the positive constraint, it means that the sub-problem is infeasible, and a new set of $(y_{sf}, y_f, y_t)$ and $x_f$ must be considered. Since $R(\mathbf{x}, \mathbf{y})$ is neither convex nor linear over the feasible set of $\mathbf{y}$, the problem is not easily solvable. An enumerative method could be used to find optimal $\mathbf{y}$ (integer variables $y_{sf}$, $y_f$, and $y_t$ have the respective upper bounds in the feasible set). The algorithm efficiency is not an important requirement in the superframe pattern design. However, developing an efficient algorithm is an interesting future work.

In our numerical example, system parameters are specified as shown in Table 1. $G_W$ and $G_T$ are design parameters and their ranges have been specified through simulation and chosen within the respective ranges. The specified values of $U_D$ and $c_R$ are based on the development specifications of ETRI's BSAN system [9].

Table 2 shows the results of our numerical example. The optimal solution vector is $(\mathbf{x}^*, \mathbf{y}^*) = (13, 4, 1024, 4, 1, 2, 2)$. With this superframe pattern, the maximum number of simultaneously active RCSTs is 208 (the number of SYNC slots per superframe) and the maximum NIR (i.e., the upper bound of the return link capacity) is $R(\mathbf{x}^*, \mathbf{y}^*) \approx 12.999$ Mbps (using QPSK and $c = 384$ bits). With 12.999 Mbps, 90 RCSTs with the maximum average rate 144 kbps, 180 RCSTs with 72 kbps, or 203 RCSTs with 64 kbps are allowable.

Table 1. Parameter values of our numerical example.

| | MHz | | μs | | # of items |
|---|---|---|---|---|---|
| $W$ | 22.4 | $U_D$ | 10000000 | $C_R$ | 200 |
| $G_w$ | 0.1 | $G_T$ | 12 | --- | --- |

Table 2. Numerical results.

| Optimal solution | | | MHz | | μs |
|---|---|---|---|---|---|
| $x_f$ | 13 | $W_{sf}$ | 22.4 | $T_{sf}$ | 6291857 |
| $x_{sync}$ | 4 | $W_f$ | 11.2 | $T_f$ | 483989 |
| $x_{trf}$ | 1024 | $W_t$ | 5.6 | $T_{csc}$ | 111 |
| $x_{cell}$ | 4 | --- | --- | $T_{acq}$ | 74 |
| $y_{sf}$ | 1 | | | $T_{sync}$ | 100 |
| $y_f$ | 2 | | | $T_{trf}$ | 472 |
| $y_t$ | 2 | | | --- | --- |

# III. CONCLUSIONS

We developed a method for optimal superframe pattern design for the DVB-RCS MF-TDMA return link so that the system data throughput is maximized. To find the optimal superframe pattern, we formulated the design problem as a non-linear combinatorial optimization problem. The proposed optimization approach can be used for throughput performance improvement in the DVB-RCS return link based on MF-TDMA.

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