

An architecture for design and planning of mobile television networks

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ABSTRACT

Mobile television (TV), made possible by the convergence of media, telecommunications and consumer electronics industries, is one of the most hyped new mobile services in several countries [1]. The advertised key features of mobile TV are personalization, interactivity, and most importantly, the ability to watch TV programming while on the go. The deployment of a mobile TV network consists of several stages that require careful planning. There are available simulation packages for designing wireless technologies, however, for mobile TV there are still planning and simulations concerns that have to be addressed in order to identify its design challenges. This article reviews the main parameters that should be taken into account to support the design and planning of a mobile TV network and proposes an architecture for its implementation.

Keywords: Mobile television, network planning, single frequency networks.

RESUMEN

El servicio de televisión móvil, que ha sido posible por la convergencia de las industrias de contenido, telecomunicaciones y electrónica de consumo, es uno de los servicios móviles emergentes más publicitados en varios países [1]. Las características más importantes anunciadas para la televisión móvil son la personalización, interactividad, y sobre todo, la posibilidad de observar programas de televisión en vivo cuando se está en movimiento. El despliegue de una red de televisión móvil consta de varias etapas que requieren una planeación cuidadosa. Actualmente se pueden encontrar programas de simulación para el diseño de diversos tipos de redes inalámbricas, sin embargo, para las de televisión móvil aún hay aspectos de planeación y simulación que se deben tomar en cuenta para cumplir con sus retos de diseño. Este artículo revisa los principales parámetros que se deben considerar durante el diseño y planeación de una red de televisión móvil, y se propone una arquitectura para la implantación de los mismos.

1. Introduction

Mobile operators are in the process of expanding their services beyond voice and short messaging, looking for new avenues of income [2]. Although 3G networks were conceived to cover new applications for mobile users, mass market for video applications is limited by spectrum availability and some other barriers that have to be addressed [3]. Some providers have decided to deploy a parallel network to support the video service independently

of the legacy applications to overcome such limitation [4].

One of the main challenges 3G networks face is that they employ an unicast approach for the video transmission. This situation creates operational pressures on the network when the number of users increases under scarcity of spectrum scenarios. There are some recent contributions [5,

6] that deal with multicast (or broadcast) transmission in Single Frequency Networks (SFN) to allow reception of the video signal by many users simultaneously.

Designing a mobile television network is a complex task [7, 8]. The underlying broadcasting network will usually represent a relatively huge investment; therefore, a careful design is critical. Network planning, sites locations and engineering are usual tasks in such a design. This paper presents an architecture for design and simulation of mobile television networks based on the Forward Link Only (FLO) standard [9]; since its modularity, it can be extended to other standards such as Digital Video Broadcasting for Handhelds (DVB-H) [10] and ATSC-M/H (Advanced Television Systems Committee - Mobile/Handheld) [11].

In Section II of this paper, we present the main technical characteristics of the FLO standard. A discussion of the analytical models employed to characterize radio channel and SFN is presented in Section III. In Sections IV and V, we present the architecture proposed and the results of the

simulation; Section V includes a case study of the proposed model for a Mexican city. Finally, in Section VI, we present the conclusions of this paper.

2. The FLO standard for mobile television

FLO is described in the TIA-1099 document [9] as an air interface for multicast multimedia transmission using single frequency networks. FLO uses Orthogonal Frequency Division Multiplexing (OFDM) with 4096 subcarriers in 5, 6, 7 and 8 MHz bandwidth channels, providing a robust service at vehicular speeds up to 200 Km/h [4, 5]. A cyclic prefix of 1/8 (92.25 μ s) of the OFDM symbol duration is used to reduce Inter Symbol Interference (ISI) and Inter Carrier Interference (ICI), in addition to accomplish signal reception from transmitters located up to 27.7 kilometers away. Also, periodic pilot symbols are inserted into the FLO signal to achieve simple filtering and reception.

Figure 1 shows a block diagram of the data channel generation process for FLO [9]. The most important blocks of the process are

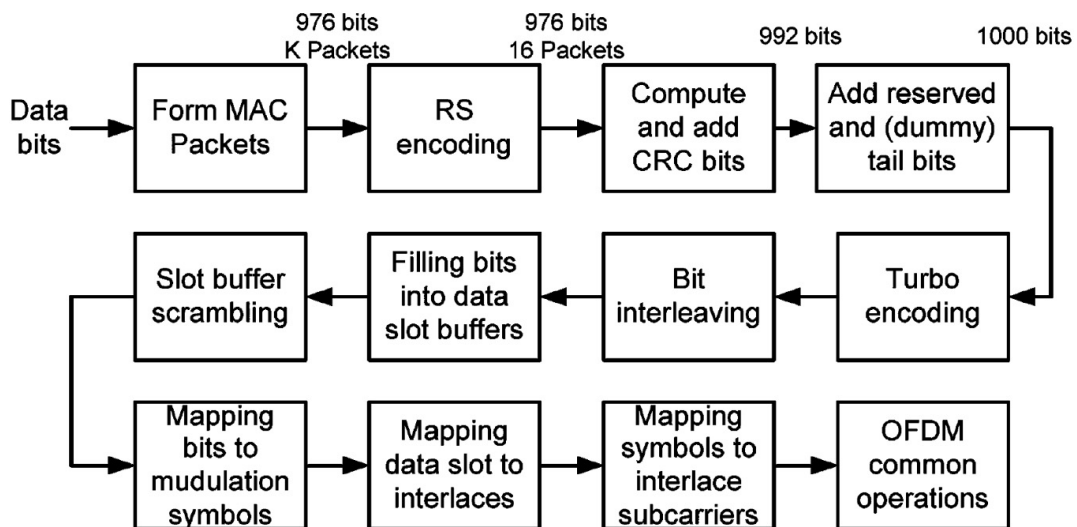


Figure 1. FLO data channel generation.

a Reed-Solomon Encoding: After K MAC layer packets are collected, the bits in each packet are grouped into 8-bit octets. Then, a Reed-Solomon (RS) encoding is performed on columns of K octets to produce N octets length codewords. The parity octets of each codeword form (N-K) new packets, as seen in Figure 2 [5].

- Cyclic Redundancy Check (CRC): After the RS code blocks are formed, 16 CRC bits are generated for each row of an RS-code block using the standard CRC-CCITT generator polynomial:

$$g(x) = x^{16} + x^{12} + x^5 + 1 \quad (1)$$

The CRC bits are used to determine, at the receiver, whether the packet was correctly decoded. This information is then used by the RS decoder to perform erasure correction.

- Turbo Encoding: The main purpose of the turbo code is to exploit the frequency-diversity inherent in the channel. It is the same turbo code defined in the cdma2000 and 1x-EV-DO standards [2, 3]. Multiple code rates are supported in FLO, typically {1/3, 1/2, 2/3}.

- Bit Interleaving: The code bits of each turbo encoded packet are interleaved such that adjacent coded bits are mapped into different constellation symbols and, for 16-QAM modulation, adjacent coded bits are alternately mapped into the more and less reliable bits in the constellation, which uses a Gray mapping. To perform the interleaving operation, an interleaver buffer consisting of N/4 rows by 4 columns is used, where N denotes the number of bits in a turbo encoded packet. The various steps in bit interleaving are exemplified in Fig. 3 [5] for the simple case of a 20 bit packet.

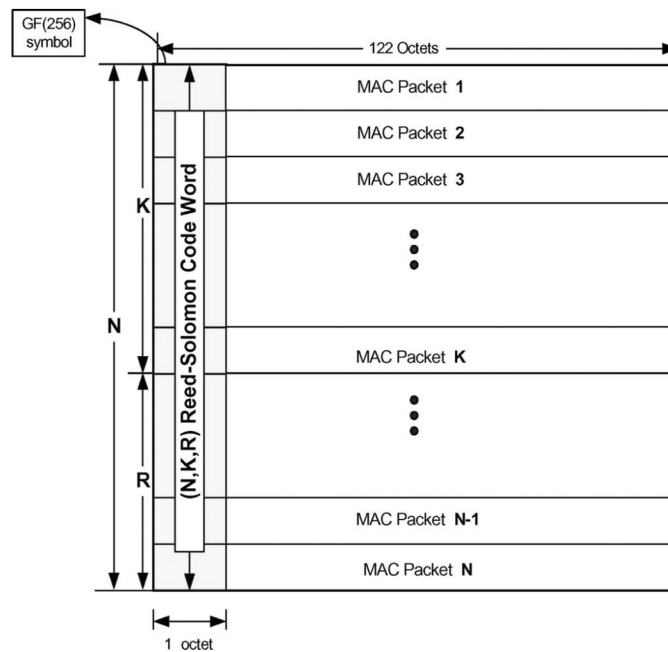


Figure 2. Reed-Solomon encoding.

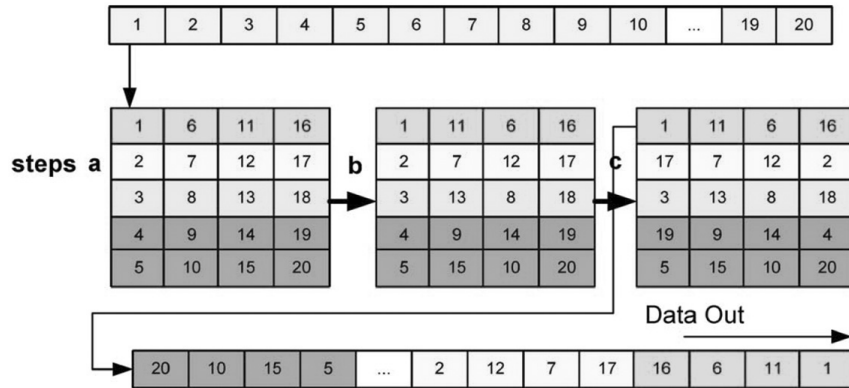


Figure 3. Bit interleaving.

- Scrambling: After the constellation symbols are grouped in *slots*, the bits in each slot are XORed sequentially with the output bits of a scrambler to randomize the bits prior to modulation. The scrambling sequence used for a slot depends on the OFDM symbol index and slot index. The sequence is produced by taking the modulo-2 inner product of the output of a 20-tap Linear Feedback Shift Register (LFSR) with the generator polynomial $h(D) = D^{20} + D^{17} + 1$, and a 20-bit mask associated with the slot index.

- Mapping bits to modulation symbols: Two or four scrambled coded bits map to a QPSK or 16QAM constellation, respectively.

The combination of different turbo code rates and modulation schemes provide different transmission modes in FLO. Table 1 shows the technical parameters for the FLO main transmission modes [9].

3. Radio propagation and Single Frequency Networks

3.1 Modeling radio channel effects

There are several key elements included in the network design and planning process that determine the coverage area of any wireless network. In order to achieve a correct characterization of the radio channel, we considered three important elements [12]: path loss, fading, and multipath. Path loss and fading define the received average power for a particular location; path losses are related to distance whereas fading takes into account the power fluctuation. Multipath is the effect of signal reflection and refraction. There are several analytic models for radio channel characterization. The models used in this work are briefly discussed as follows:

Mode	Modulation	Turbo Code Rate	Data Rate (Mbps)
0	QPSK	1/3	2.8
1	QPSK	1/2	4.2
2	16-QAM	1/3	5.6
3	16-QAM	1/2	8.4
4	16-QAM	2/3	11.2

Table 1. FLO main transmission modes.

a) *Hata model for path loss*: This model predicts total path loss along a link of terrestrial microwave or other type of cellular communications. We selected Hata model having in mind that computation time is very short [13], as only four parameters are required. We also considered that Hata model has the advantage to apply a general formula for urban scenarios and correction factors for suburban and rural scenarios. This is especially useful for cities with rural or suburban communities around the metropolitan area. The Hata equation for path loss in an urban area is

$$L = 69.55 + 26.16 \log f_0 - 13.82 \log h_T + a(h_R) + (44.9 - 6.55 \log h_T) \log d \quad (2)$$

where

150 ≤ f₀ ≤ 1500 MHz (operating frequency)
 30 ≤ h_T ≤ 200 m (transmitter antenna height)
 1 ≤ h_R ≤ 10 m (receiver antenna height)
 1 ≤ d ≤ 20 Km (distance between transmitter and receiver)

The term a(h_R) is an antenna height correction factor that depends upon the environment; in the case of a medium to small city:

$$a(h_R) = (1.1 \log f_0 - 0.7) h_R - (1.56 \log f_0 - 0.8) \quad (3)$$

For a large city and f₀ > 300 MHz:

$$a(h_R) = 3.2 (\log 11.75 h_R)^2 - 4.97 \quad (4)$$

The adjustment for path loss in a suburban area is

$$L = L(\text{urban}) - 2 [\log(f_0/28)]^2 - 5.4 \quad (5)$$

Finally, for open and rural areas the adjustment is

$$L = L(\text{urban}) - 4.78 (\log f_0)^2 + 18.33 \log f_0 - 40.94 \quad (6)$$

b) *Zheng and Xiao model for signal fading*: In wireless communications, fading occurs when there

are objects in the environment that scatter the radio signal before it arrives at the receiver. The fading may vary with time, geographical position and radio frequency, and is often modeled as a random process. In our work, we choose the fading model proposed by Zheng and Xiao since it converges faster and improves statistical quality compared to other models [14].

According to [14], a normalized fading can be defined as the sum of sinusoidal signals described by

$$\mu(t) = \mu_C(t) + j\mu_S(t) \quad (7)$$

$$\mu_C(t) = \frac{2}{\sqrt{M}} \sum_{n=1}^M \cos(\psi_n) \cos(\omega_d t \cos \alpha_n + \varphi) \quad (8)$$

$$\mu_S(t) = \frac{2}{\sqrt{M}} \sum_{n=1}^M \sin(\psi_n) \cos(\omega_d t \cos \alpha_n + \varphi) \quad (9)$$

$$\alpha_n = \frac{2n\pi - \pi + \theta}{4M}, n = 1, 2, 3, \dots, M \quad (10)$$

where θ, φ and ψ_n are statically independent and uniformly distributed in the [-π, π] interval for every n, and ω_d is the Doppler frequency in radians.

c) *COST 207 model for multipath*: Multipath phenomenon results in radio signals reaching the receiving antenna by two or more paths. Causes of multipath include ionosphere reflection and refraction, and reflection from terrestrial objects such as mountains and buildings. The effects of multipath include constructive and destructive interference, and phase shifting of the signal, resulting in a frequency-selective time-varying channel that can be represented as the sum of L propagation paths, given by

$$\bar{h}(t', t) = \sum_{n=0}^{L-1} \bar{a}_n \bar{u}_n \delta(t'_n - t) \quad (11)$$

where n is the multipath number, \bar{a}_n is the average multipath power, \bar{u}_n represents the fading process, and $\partial(t'_n-t)$ is the multipath delay related to the first arriving multipath.

The European COST 207 project specified typical values for multipath power and delay in different propagation environments as a result of propagation measurements carried out in different countries [15, 16]. Typical propagation environments were defined as Rural Area (RA), Typical Urban (TU), Bad Urban (BU, densely built urban areas with bad propagation conditions), and Hilly Terrain (HT).

3.2 Single Frequency Networks

A Single Frequency Network (SFN) is a broadcast network where several transmitters simultaneously send the same signal over the same frequency channel. Several echoes of the same signal arrive at the receiving end resulting in constructive or destructive interference among them [17]. OFDM modulation reduces destructive interference since it uses a large number of slow low-bandwidth modulators and a guard interval (cyclic prefix) between the symbols.

For a single frequency network with several transmitters x_n the received signal $y(t)$ is obtained as

$$y(t) = \sum_n x_n(t) * h_n(t) + n(t) \quad (12)$$

If we receive the same signal $x(t)$ with different time offsets τ_n , i.e.

$$x_n(t) = x(t - \tau_n) \quad (13)$$

we obtain:

$$y(t) = x(t) * \sum_n h_n(t - \tau_n) + n(t) \quad (14)$$

Therefore, the equivalent transmission model of a single frequency network is similar to the transmission model for multi-path transmission between one transmitter and one receiver, with a more complex and longer impulse response. The impulse response is considered time-invariant for one symbol but is allowed and expected to change between symbols.

In a three-transmitter SFN, like the one shown in Figure 4, we can have three possible scenarios [18]: Figure 4(a): Signals arriving at the same time (constructive interference, ideal case); Figure 4(b): Two signals arriving at the same time, the third one is delayed; if the delay is smaller than the cyclic prefix, we experience constructive interference, otherwise, the contribution could be negative. Finally, Figure 4(c) shows the general case, where the three signals arrive at different times; positive or negative interference will depend on the magnitude of the delay with respect to the first arriving signal.

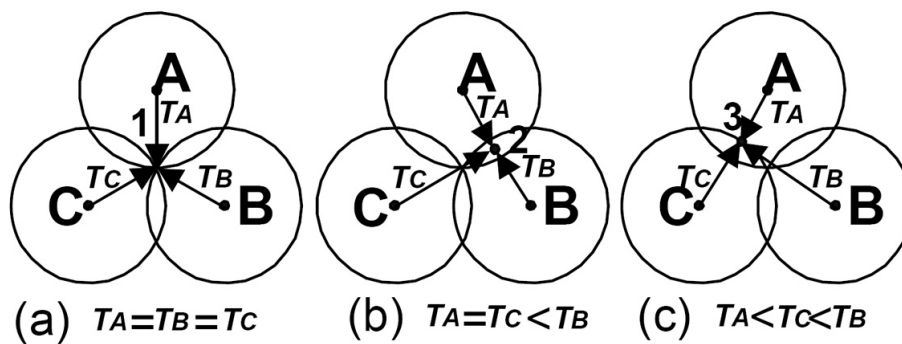


Figure 4. Interest points for a three-transmitter SFN scenario.

4. Architecture design

Once we identify the main technical characteristics of FLO, the radio channel, and SFN, we proceed to build an architecture for design, planning and simulation of mobile television single frequency networks, which is depicted in the block diagram in Figure 5.

We consider as inputs for the simulation architecture: a) the desired FLO transmission mode (0 to 4), which must be identical for both the transmitter and the receiver; b) number of transmitters, with its location and power; and c) the environment type of the area to simulate (rural, typical urban, bad urban, or hilly).

Having defined the transmission mode, all the processes to generate an FLO signal (Figure 1) can be carried out; inverse processes are applied to recover the input signal. During the simulation, the power and location of the transmitters are fixed, not so for the receiver end, which moves through the entire coverage area of the SFN, so in our simulation a footprint of the received signal quality is obtained. The received signal is affected by path loss, multipath, and fading, as described in Section III.1. The effect of constructive or destructive interference from all the transmitters on the SFN is evaluated as discussed in Section III.2. A simulation model for this architecture was implemented in Matlab 2008a (see Figure 6). The simulation model is modular so it can be easily adapted to different mobile television standards.

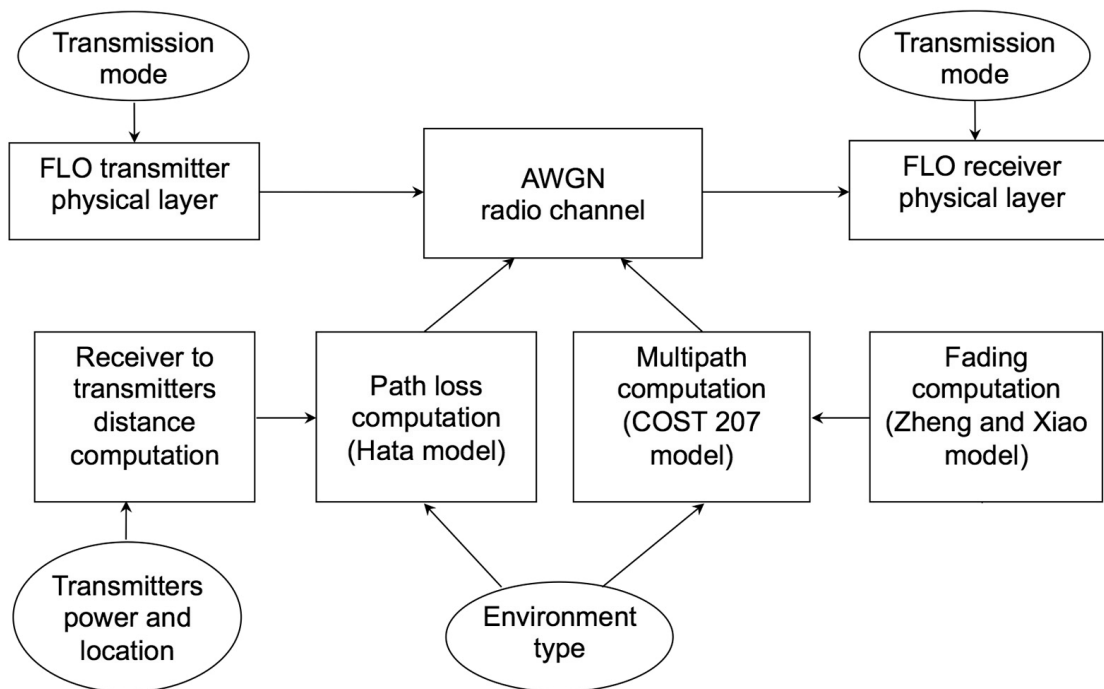


Figure 5. Block diagram of the proposed simulation architecture.

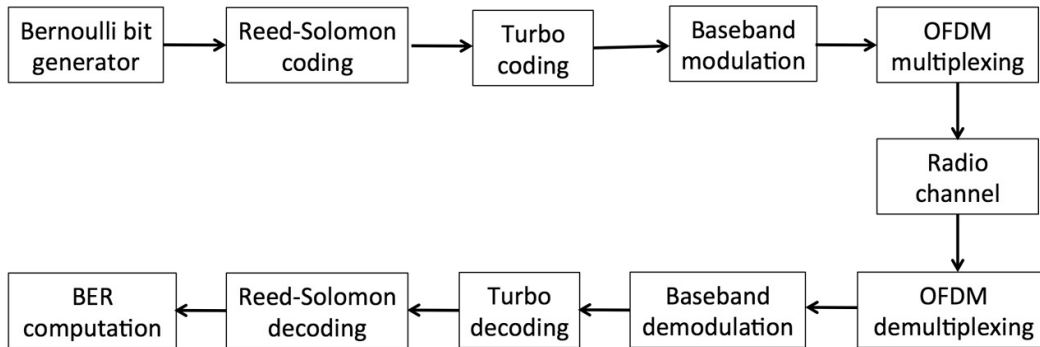


Figure 6. Block diagram for Matlab implementation of the proposed architecture.

5. Simulation and results

The simulation model built from the proposed architecture can be used as a tool to support the design and planning process of a mobile television SFN. The model provides valuable information regarding key design parameters such as Bit Error Rate (BER) performance versus distance between transmitters. Results for a three-transmitter SFN like the one in Figure 3 are shown in Figures 7, 8, and 9 for rural, urban, and dense urban environments, respectively. The simulation parameters are listed in Table 2.

Results in Figure 7, corresponding to a rural environment, show that if a BER of 10^{-3} or less is required for acceptable video quality [5], the maximum distance between transmitters is 27 kilometers for FLO mode 4, whereas in mode 0, the distance between transmitters can be extended to 35 kilometers because of its lower data transmission and BER constrains. This is due to the fact that mode 0 is more resilient to channel impairments given its higher error correction rate (1/3) and robust modulation scheme (QPSK), as shown in Table 1.

Parameter	Value
OFDM symbol rate	1200 sym/seg
Reed-Solomon code rate	(16,12)
Bandwidth	6 MHz
Transmission power	50 KW
Frequency	701 MHz
Transmitter height	60 m
Receiver height	1.5 m

Table 2. FLO main transmission modes.

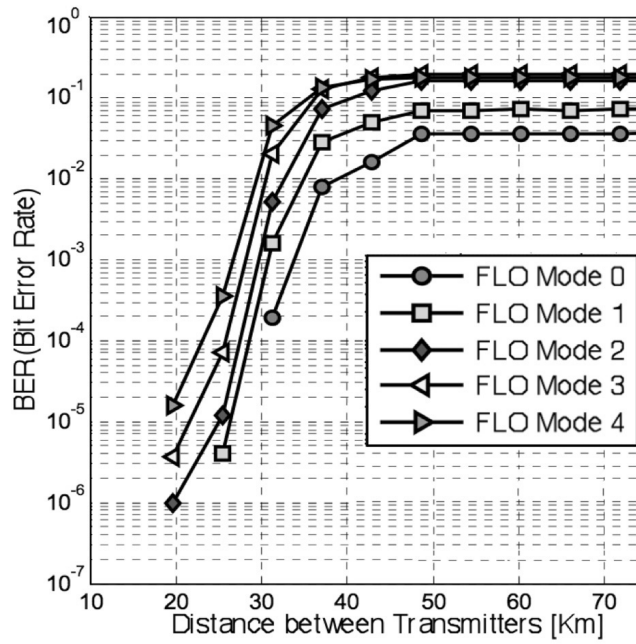


Figure 7. BER vs. distance between transmitters (rural environment).

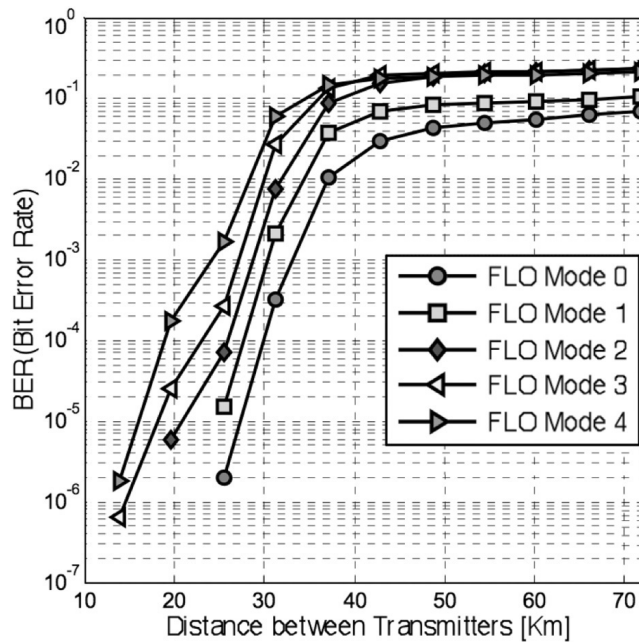


Figure 8. BER vs. distance between transmitters (urban environment).

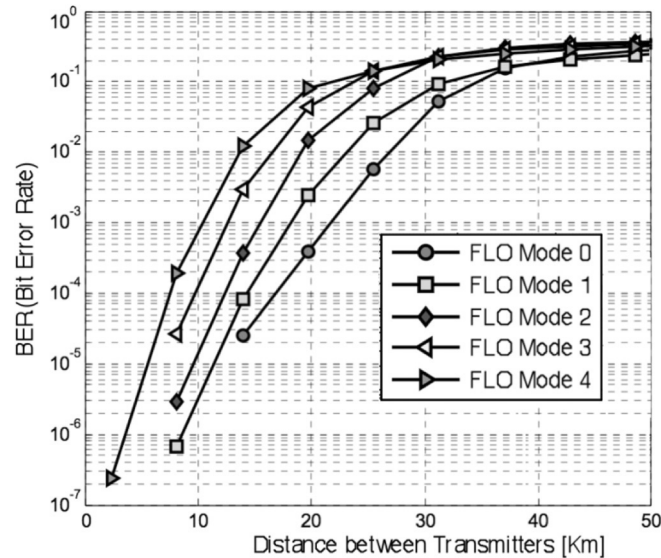


Figure 9. BER vs distance between transmitters (dense urban environment).

However, with mode 0, the number of television channels is limited by the maximum data rate achievable; besides, delay fluctuations due to extended range may cause undesired interferences. Figure 8 shows similar results for an urban environment, and Figure 9 shows that adverse effects of multipath in dense urban environments limit the distance between transmitters to 11 kilometers for mode 4 and 22 kilometers for mode 0.

5.1 Case study: mobile television network for Mexicali, Mexico

Mexicali, capital city of the state of Baja California, is located in Northwestern Mexico at the common border with the state of California in the United States of America (USA). Although the regulatory aspects of frequency coordination required for any spectrum use in the common border of both countries were not considered in this paper, Mexicali provides a scenario with geographic and demographic characteristics suited for a basic simulation analysis.

The valley of Mexicali covers an urban area of around 100 Km² and a rural area close to 2000

Km². San Luis Rio Colorado, in the neighboring state of Sonora, is the closest urban area. For practical purposes, our simulation considered a transmitter in each one of these two cities, with 50 KW and 15 KW of transmission power, respectively. A distance between transmitters of 52.97 kilometers was found. We selected television channel 47 to run our simulation taking into account that this channel is available in the frequency coordination plan between the regulatory administrations of Mexico and USA [19]. Channel 47 operates at 671 MHz with 6 MHz of bandwidth.

Figures 10 and 11 show BER footprints for FLO transmission modes 0 and 4, respectively. For BER less than 10⁻³, the network covers an area of 2,394 Km² in mode 0, while in mode 4 coverage area is reduced to 339 Km². Areas of service with the required BER can be selected to study the effects on other key parameters of the network design and planning, which include the financial and demographic data. In other simulation runs, we also could observe that the simulation model presented in this paper can be helpful to identify areas of potential constructive or destructive interference due to changes in the transmission mode, transmission power or data transmission rate.

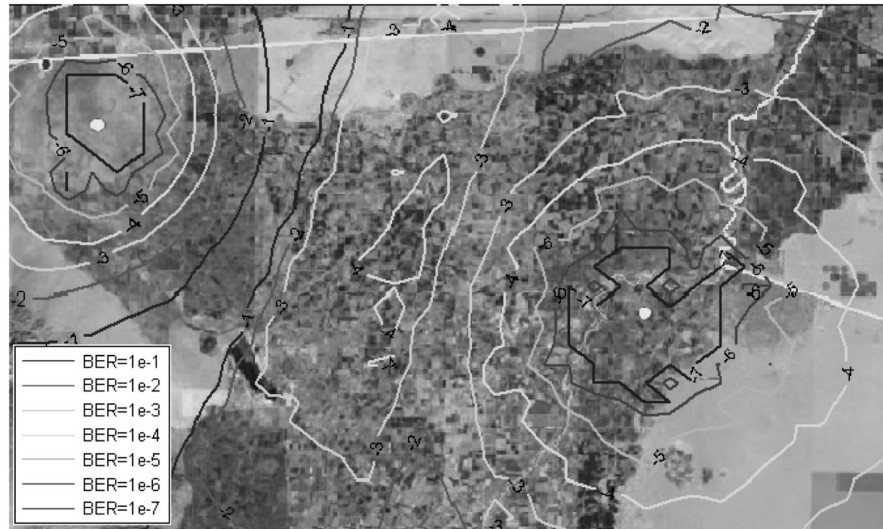


Figure 10. FLO mode 0 BER footprint for Mexicali.

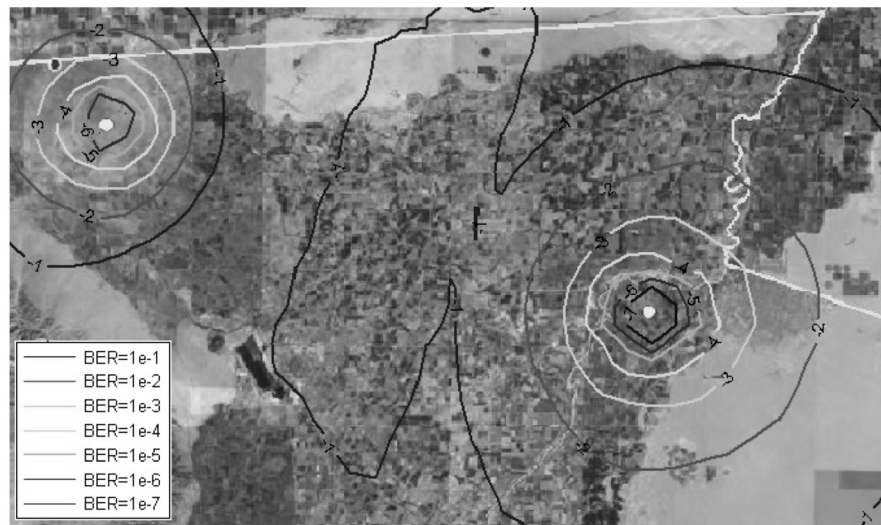


Figure 11. FLO mode 0 BER footprint for Mexicali.

6. Conclusions

In countries like Mexico, with limited information regarding the levels of penetration of emerging technologies like mobile television, it becomes useful for service providers to assess the interrelation of the main technical issues involved in the deployment of a new network. In this paper we proposed an architecture for simulation of mobile television networks that includes the main factors that impact its performance. The results obtained from simulations can support the processes of design and planning for a mobile television network, and can be a basic tool for determining its technical and financial feasibility.

The proposed simulation model provides the features and flexibility to integrate a simple simulation platform to obtain scenarios that consider, among others, the following factors: the locations of the transmitters, the topology of the network, the mobility of the receiving terminal, and different types of environment.

6.1 Future work

Since Mexico has not defined a standard for mobile television, we are currently building simulation blocks to extend the proposed model to standards like DVB-H and ATSC-M/H. We are also working on a GUI (Graphical User Interface) to develop a more user-friendly simulation model.

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