Performance Analysis of Satellite-HSDPA Transmissions in Emergency Networks

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Abstract. In this work we are interested to investigate how the Geostationary (GEO) satellite can be used to employ efficiently High Speed Downlink Packet Access (HSDPA) technology supporting Multimedia Broadcast/Multicast Service (MBMS) in a scenario in which the terrestrial network is not available. An exhaustive simulation campaign has been carried out with the aim to determinate the Satellite-HSDPA (S-HSDPA) performances in different radio channel conditions. In particular, a Good/Bad Channel model has been taken into account to achieve a specific radio information and to be able to evaluate the maximum date rate that can be obtained by S-HSDPA.

Keywords: GEO satellite, HSDPA, MBMS, Good/Bad channel.

1 Introduction

Nowadays, Third Generation (3G) cellular wireless networks, such as Universal Mobile Telecommunication System (UMTS), are able to provide support to mobile videoconferences, multimedia streaming (i.e. TV on mobile phones), broadband transmissions and downloading services [1]. Notwithstanding, a terrestrial-only segment may not be adequate to environments exhibiting high exacting communication requirements. It is the case of so called disadvantaged areas: either rural areas or areas involved in unpredictable catastrophic events. This is why the integration of space segments into the UMTS architecture deserves a special attention from the scientific and industrial communities involved in the design of *Emergency Networks*.

UMTS network, already, foresees also a satellite component, called Satellite-UMTS (S-UMTS), aiming to provide services to mobile users in such scenarios. According to [2], [3] the following important purposes can be highlighted that justify the need for integration of S-UMTS in the terrestrial system: *(i) Geographical complement,* as an extension of covered area where the only Terrestrial-UMTS (T-UMTS) is not adequate or not available; *(ii) Personal universal communications,* as an omnipresent scenario in order to realize an *anyone*, *anywhere* and *anytime* cellular applications distribution.

In an *Emergency Scenario*, the limited radio resources of satellite component have to be efficiently utilized, in order to allow the information exchange among rescue teams. Indeed, many groups of first responders may need to be established and to share logistic information of various nature, e.g. dispatching, maps, video of the incident area, etc.. The employment of High Speed Downlink Packet Access (HSDPA) technology [4] supporting Multimedia Broadcast/Multicast Services (MBMS) in satellite network can enhance the overall system performance, since on one side HSDPA increases the date rate with respect to standard UMTS and on the other hand, multicast emergency transmissions can be delivered to groups of receivers at the same time; thus avoiding data duplications both in the core network and over the air interface.

Several research works have been conducted, targeted to study the HSDPA for MBMS applications taking into account both terrestrial network and High Altitude Platforms (HAPs). For instance, in [5] authors demonstrated that the maximum number of users served by the High Speed Downlink Shared Channel (HS-DSCH) hardly depends on the User Equipment (UE) speed. Instead, in [6], [7] authors made some performance study of HSDPA for PtM MBMS applications; while in [8], [9] authors introduced the use of HAPs for supporting the terrestrial networks in disadvantaged areas.

This paper aims at investigating the possibility to provide connectivity via Geostationary (GEO) satellite to rescue teams and first responders involved in the incident area. In particular, a preliminary study on Satellite-HSDPA (S-HSDPA) performances have been conducted with the purpose to evaluate the maximum amount of resources (in term of *Data Rate*) that a S-HSDPA can provide. In case of Terrestrial-HSDPA (T-HSDPA) the Adaptive Modulation and Coding (AMC) technique allows changing the kind of modulation depending on the radio channel conditions. In particular, the Channel Quality Information (CQI) includes this information; in fact, the transport block size, the number of used physical channels and the kind of modulation are evaluated from the CQI value [4].

Such information depends on the channel conditions sensed by the UE, exchanged with the Terrestrial Radio Network Controller (T-RNC). In fact, the T-RNC receives the CQI reported from the UE every 2 ms; for instance, if such a CQI indicates that the Quality of Service (QoS) is worsening, the T-RNC can select a more robust ACM level. In case of satellite transmission scenarios different propagation features must be considered to be able to investigate the performance of the S-HSDPA, used in *Emergency Networks*.

Therefore, considering that we took into account both fixed and mobile users, in the case of fixed users is assumed that terminals have a Line-of-Sight (LoS) path loss to the GEO satellite, while for mobile scenario a classic *Good/Bad channel* model has been utilized to take into account the different radio channel conditions. In the *Good/Bad channel*, state fluctuations are due to shadowing phenomena that mainly depend on the mobile environment. Basically, the *Good channel* is characterized by an unshadowed LoS path loss, while the *Bad channel* is related to shadowed periods of Non LoS (NLoS) path loss [10].

The paper is organized as follows. Section 2 provides a general overview of HS-DSCH channel. Then, in Section 3 we illustrated the experiment scenario, including the description of the considered S-UMTS scenario and the radio channel conditions highlighting the differences between *Good* and *Bad channel*. The results of an exhaustive simulation campaign are the focus of Section 4. While, conclusive remarks are given in Section 5.

2 HS-DSCH Description

HS-DSCH is the shared transport channel carrying the user data with HSDPA that is the downlink transmission component of the High Speed Packet Access (HSPA) technology. In a wireless network environment, the selected Energy per Bit-to-Spectral Noise Density (E_b/N_0) is equivalent to a certain Block Error Rate (BLER) for a particular application bit rate. Nevertheless, the E_b/N_0 is not a suitable metric for HSDPA because the bit rate on the HS-DSCH can change every Transmission Time Interval (TTI), by using different modulation schemes, code rates and physical channel codes. Therefore, in the HS-DSCH scenario, the E_b/N_0 is taken over from the Signal to Interference Noise Ratio (SINR) representing a more suitable measurement metric as it is independent of the considered modulation. Equation (1) illustrates this parameter.

$$SINR = SF_{16} \frac{P_{HS-DSCH}}{pP_{own} + P_{other} + P_{noise}} \qquad (1)$$

In the equation $P_{HS\text{-}DSCH}$ represents the transmission power assigned to the HS-DSCH, P_{own} is the own cell interference, P_{other} is the neighbouring cells interference, P_{noise} is the Additive White Gaussian Noise (AWGN), p is the orthogonality factor (that can be zero in the case of perfect orthogonality), while SF_{16} is the SF value fixed to 16 for the HS-DSCH [4].

The main goal of HSDPA is to raising user data rates enabling a utilization of different applications characterized by diverse QoS requirements. The shorter TTI compared to the WCDMA one and the implementation of the scheduling functionalities in the Node-B, allow a fast adaptation to the channel state variations [4]. Such state variations affect the SINR that in turn, how it will be clarify in Section 4, changes the CQI values.

The state of the satellite channel information is obtained thanks to the uplink data (CQI measurements) sent from the UE in according to the *Good/Bad Channel* model. The long propagation delays could make CQI measurements useless, notwithstanding, different delay compensation techniques are proposed in literature to solve this kind of problem, for instance in [11] a possible solution is proposed for Ku and Ka band satellite links.

In the next sections the impact of the new radio channel conditions to the SINR will be explain.

3 Experiment Scenario

In this section we explain the main features of the GEO satellite radio interface suggested by the Satellite Earth Stations and Systems Technical Committee of the European Telecommunications Standards Institute (ETSI) and taken into account in our research work. The satellite channel varies from the terrestrial one in terms of the following propagation features: *(i)* longer propagation delay (120 ms satellite to earth delay for GEO satellite); *(ii)* Doppler effects; *(iii)* path loss; *(iv)* multipath fading; *(v)* interferences; *(vi)* effect of the distance from the centre of the area covered by the satellite, being equidistant from all users. Moreover, the satellite radio interface is compatible with the 3GPP WCDMA radio one; hence, it is also compatible with the band at 2 GHz for the 3G devices. Such an issue clearly gives the advantage to smooth over the impact of the *satellite enabled terminals* cost, guarantying interoperability with the 3G environment [12].

In our research study, we considered a multi beam GEO satellite; the scenario is shown in Figure 1.

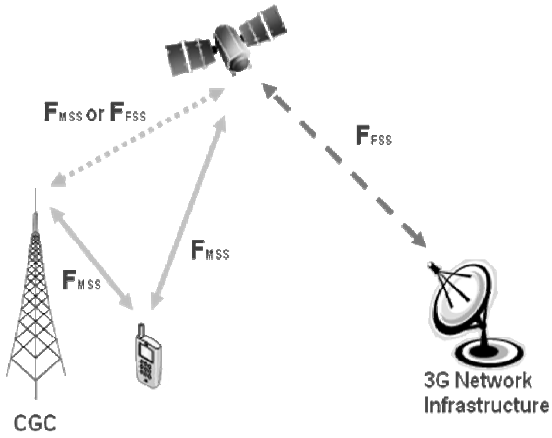

Figure 1. S-UMTS architecture including a GEO satellite.

All the features of the Radio Access Network (RAN) representing the network part are located in the gateway; then we considered that all the UEs distributed in the domain of a particular gateway stay in the coverage area managed by it. The gateway configures the physical layer of the radio interface using the protocol of the 3GPP radio interface, to smooth over the satellite channel features. Hence, the UE radio access parameters are configured by the RAN and sent to UE over the radio interface. From the figure we can notice that there exist two different ways to send data to the UEs; in fact, either a direct link between satellite and UEs and a Complementary Ground Component (CGC), which relays signals to/from the satellite, can be used. In our study we deal with transmission data by the link between the satellite and the UEs.

Different kinds of UEs can work in case of satellite coverage such as handset or vehicular. In the uplink direction the codes orthogonality is kept in 99% of the cases.

In our study we considered 62.5 dBW Equivalent Isotropically Radiated Power (EIRP) per spot, a satellite antenna C/I of 12 dB, a GEO satellite located at an altitude of 35800 km covering an area with a radius equal roughly to 600 km.

As we already said, a *Good/Bad Channel* model has been taken into account in our research work; the *Good channel* is related to an unshadowed LOS path loss, while the *Bad channel* is characterized by shadowed intervals of NLOS path loss. In particular, in case of NLOS we considered a further *loss element* of the signal transmitted by the satellite, named *excess path loss*. This contribution of the path loss depends on the following parameters: *(i)* local environment; *(ii)* vehicle heading; *(iii)* link frequency; *(iv)* satellite elevation angle; *(v)* street side. In [13] is highlighted how the first two contributions dominate and how the *excess path loss* is equal to a value between 10 dB (in suburban areas) and 25 dB (in urban situations). In our research work we considered the worse case (i. e. 25 dB) in case of *Bad Channel*.

Moreover, time intervals of *Good* and *Bad channel* are characterized by an exponential distribution. The average time period in the *Good state* (T_g, i.e. when LOS path loss is experienced) and the one in the *Bad state* (T_b, i. e. when instead a NLOS path loss including the *excess path loss* is experienced) depend on the power value sensed by the terminals and on the UE speed varying from LOS to NLOS condition and vice versa. Equations (2) and (3) illustrate T_g and T_b [12].

$$T_g = \frac{e^{\eta} - 1}{f_D \sqrt{2\pi\eta}} \quad (2)$$

$$T_b = \frac{1}{f_D \sqrt{2\pi\eta}} \quad (3)$$

Where f_D is the Doppler shift obtained as:

$$f_D = \frac{V f_p}{c} \quad (4)$$

Where V represents the average UE speed, c is the light speed and f_p is the carrier frequency. While, η defined by (5) is the ratio between the threshold power level P_t, which enables to distinguish amongst the *Good channel* and the *Bad channel*, and the Root Mean Square (RMS) value of the interference power value, P_{rms}.

$$\eta = \frac{P_t}{P_{rms}} \quad (5)$$

The fading model that we have taken into account in our simulations is also strictly related to the channel condition. In particular, in case of *Good channel* we considered the state with the Rician probability Density Function (PDF) that represents unshadowed areas with relatively high received signal power; while in case of *Bad channel* we took into account the state with Rayleigh-Lognormal PDF, representing shadowed areas with low received signal power [14].

4 Obtained Results

The purpose of the realized simulation campaign is to investigate how the satellite can be utilized to employ efficiently HSDPA technology supporting MBMS in *Emergency Network*. To do that we studied how the *Good* and *Bad channel* conditions affect the SINR that has to be assured and then the maximum *Data Rate* that the Satellite-HS-DSCH (S-HS-DSCH) can support. Furthermore, we took into account the UE speed equal to 3 km/h.

Firstly, as the SINR is strictly linked to the assigned S-HS-DSCH transmission power and on the state of the channel, in Figure 2 we illustrate the SINRs that have to be guaranteed when changing the cited parameters. As expected the assured SINR improves when the S-HS-DSCH assigned power value increases and in case of *Good channel*.

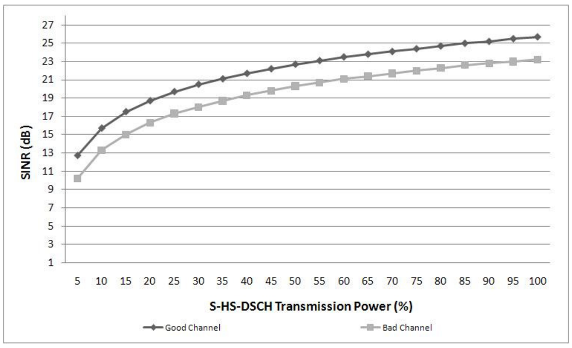

Figure 2. SINR vs S-HS-DSCH Transmission Power.

Moreover, in HSDPA, the maximum *Data Rate* depends on the CQI that, in turn, is closely connected to the SINR values. Indeed, the CQI parameter varies in according to channel conditions experienced by the UE. For each CQI value are associated the transport block size, the number of used physical channels, the modulation technique and, finally, the *Data Rate* (see Table 1).

It is worth noting that values reported in Table 1 are applicable for both terrestrial and satellite systems. In this work, the Satellite-HSDPA coding and modulation chains has been implement by using Simulink to determinate the maximum *Data Rate* that satellite system can provide. An exhaustive simulation campaign has been carried out.

Figure 3 and 4 illustrate the SINRs to be guaranteed for different values of CQIs and BLERs, when the state of channel is *Good* and *Bad* respectively. Obviously, in case of *Good channel* the better radio channel condition allows obtaining a higher CQI keeping the same SINR and as a consequence a higher *Data Rate*. From the matching of obtained results and the values reported in Table 1, it is possible to determinate the maximum *Data Rate*, that satellite systems can provide in *Good* and *Bad* channel conditions for a desired Block Error Rate (BLER) and a given HS-DSCH transmission power.

Table 1. HS-DSCH Parameters.

CQI	Modulation	#Physical Channel	Data Rate (kbps)
1	QPSK	1	68.5
2	QPSK	1	86.5
3	QPSK	1	116.5
4	QPSK	1	158.5
5	QPSK	1	188.5
6	QPSK	1	230.5
7	QPSK	2	325.5
8	QPSK	2	396
9	QPSK	2	465.5
10	QPSK	3	631
11	QPSK	3	741.5
12	QPSK	3	871
13	QPSK	4	1139.5
14	QPSK	4	1291.5
15	QPSK	5	1659.5
16	16-QAM	5	1782.5
17	16-QAM	5	2094.5
18	16-QAM	5	2332
19	16-QAM	5	2643.5
20	16-QAM	5	2943.5
21	16-QAM	5	3277
22	16-QAM	5	3584
23	16-QAM	7	4859
24	16-QAM	8	5709
25	16-QAM	10	7205.5
26	16-QAM	12	8774
27	16-QAM	15	10877
28	16-QAM	15	11685
29	16-QAM	15	12111
30	16-QAM	15	12779

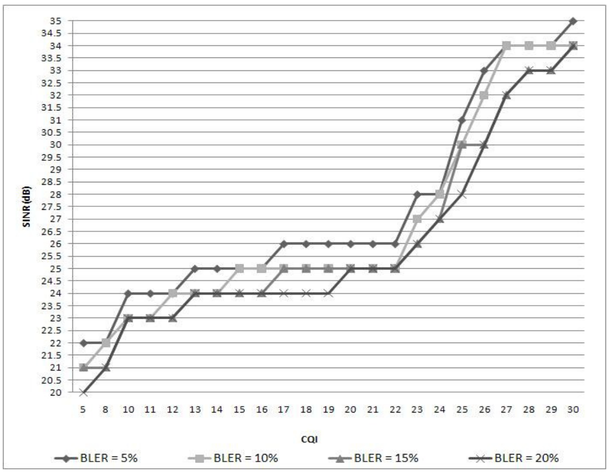

Figure 3. SINR vs CQI in case of Good Channel.

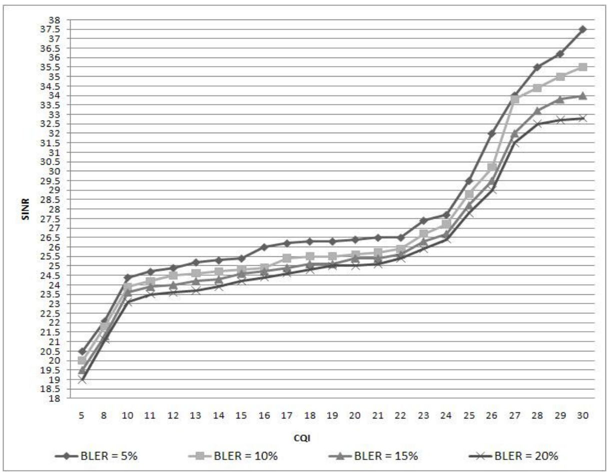

Figure 4. SINR vs CQI in case of Bad Channel.

Figure 5 is a graphical representation of this *Data Rate*, obtained when varying S-HS-DSCH transmission power and channel state, given a target BLER of 10%. In case of T-HSDPA the transmission power assigned to the T-HS-DSCH can vary between 35 and 60% of the overall transmission power, nonetheless we assumed that the values of S-HS-DSCH transmission power can reach out the overall transmission power because we are supposing a GEO satellite used only for S-HSDPA applications.

From the figure clearly emerges how the transit from *Good channel* to *Bad channel* lead to a considerable reduction of the *Data Rate*. This means that in case of change of the radio condition channel some rescue team could lose suddenly the connection. Therefore, obtained results besides giving a performance analysis of S-HSDPA supporting MBMS applications, can be further utilized to introduce the main requirements of possible RRM policies that aim to maximize the system capacity and the number of services that a satellite network can provide in a disaster area.

Hence, to avoid losing the connection of a considerable group of rescue teams, the following approaches could be taken into account: *(i)* during the low intervals of *Bad channel* the BLER target can be made worse, then changed to 20%, decreasing the QoS but at the same time safeguarding the connection of several UEs; *(ii)* the greater *Data Rate* of *Bad Channel* (i.e. 631 kbps) could be used to provide the PtM services. So doing it will be possible to have one (or more than one) multicast group of rescue teams able to receive streaming services without loss of connectivity employing the PtM transmission of HSPA. The remaining resources will be used to provide delay tolerant services, such as file downloading, messaging and so on. Hence, rescue teams can obtain continuously MBMS data with a lower but guaranteed *Data Rate* (in the *Bad Channel* conditions) and they can take advantage of the additional *Data Rate*, provided from the better conditions of the *Good state*, for downloading delay tolerant files such as maps or messages from other teams; *(iii)* the power assigned to S-HS-DSCH can be dynamically modified in according to the channel conditions. Indeed, from Fig. 5 one can notice that the greater *Data Rate* can be obtained using only the 80% of the overall S-HS-DSCH transmission power in case of *Good channel* and the

95% in case of *Bad channel*. Hence, the saved power could be used to provide services on dedicated channels.

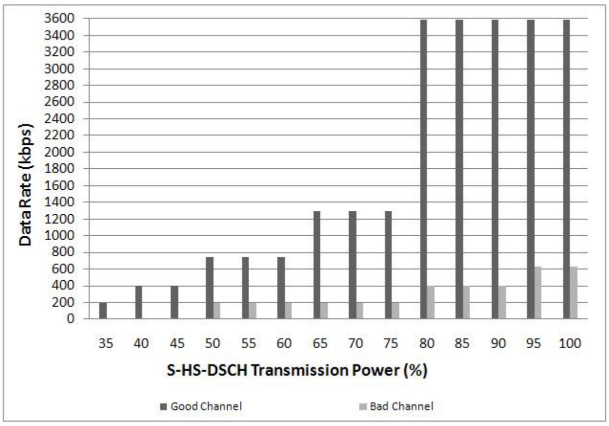

Figure 5. Data Rate vs S-HS-DSCH Transmission Power, with BLER 10%.

5 Conclusions

In the last few years the UMTS is supported by a satellite component, defined as S-UMTS. The goal of this research work was to investigate the HSDPA performance in a Satellite environment (S-HSDPA) in which the terrestrial network is not available. The maximum Data Rate has been evaluated when a Good/Bad Channel model was taken into account for the satellite link. Furthermore, as a future work obtained results can be used to introduce RRM policies with the purpose to improve the performance of S-HSPA system.

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