Link Cooperation Technique for DVB-S2 Downlink Reception with Mobile Terminals

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Abstract. Direct reception of DVB-S (2) satellite signals from mobile terminals equipped with non directive antennas is becoming of great interest among manufacturers and operators. Low orbit constellations are technically preferred for mobile terminal reception due to the reduced path loss. Economical issues however, have recently redirected the interest to medium and geostationary constellations, eventually assisted by high altitude platforms. The satellite power is limited by technology and the maximum allowable mass of satellites. This work explores the opportunity of application of link cooperation techniques for downlink reception of DVB-S (2) bitstreams.

1 Introduction

DVB-S(2) is the second generation system for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications [1,2]. This system gets advantages from the most recent developments of channel coding LDPC, joined with several modulation orders (QPSK, 8-PSK, 16-APSK and 32-APSK). The possibility to change the modulation and coding parameters for each frame (VCM) and the ability to change these parameters according to the channel (ACM), are the main new system characteristics.

Direct reception of DVB-S2 satellite signals from mobile terminals, equipped with non directive antennas, is becoming of great interest among manufacturers and operators. Low orbit constellations are technically preferred for mobile terminal reception due to the reduced path loss. Economical issues however, have recently redirected the interest to medium and geostationary constellations, eventually assisted by high altitude platforms. Since the satellite power is limited by technology and the maximum allowable mass of satellites, downlink EIRP is a limited resource which can be increased at the expense of coverage, by reducing the spot dimensions [3]. Even in the latter case, a sufficient C/N value cannot be reached by the receiver handset for the correct reception of the DVB-S(2) downstream. Recently, a new class of methods called *cooperative communication* has been proposed [4,5,6], that enables single-antenna mobiles in a multi-user environment to share their antennas and generate a virtual multiple-antenna transmitter that allows them to achieve transmit/receive diversity. The mobile wireless channel suffers from fading, meaning that the signal attenuation can vary significantly over the course of a given transmission. Transmitting/receiving independent copies of the signal generates diversity and can effectively combat the deleterious effects of fading. In particular, spatial diversity is generated by transmitting/receiving signals from different locations, thus allowing independently faded versions of the signal at the receiver. Cooperative communication generates this diversity in a new and interesting way.

The main cooperation strategies are Detect and Forward [4,5], Amplify and Forward [6] and Selective Forward [7]. The considered cooperation scheme in this paper is Amplify and Forward (AF) [8].

2 System Model

The adopted cooperation scenario is depicted in Fig. 1. The main operating parameters are reported in Table 1.

The basic idea of AF strategy [8] is that around a given terminal, there can be other single-antenna terminals which can be used to enhance diversity by forming a virtual (or distributed) multiantenna system (see Fig. 1) where the satellite signal is received from the active terminal and a number of cooperating relays. The cooperating terminals retransmit the received signal after amplification. The AF strategy is particularly efficient when the cooperating terminals are located close to the active one so that the cooperative links ($c(1)$,$c(2)$,$c(3)$) are characterized by high

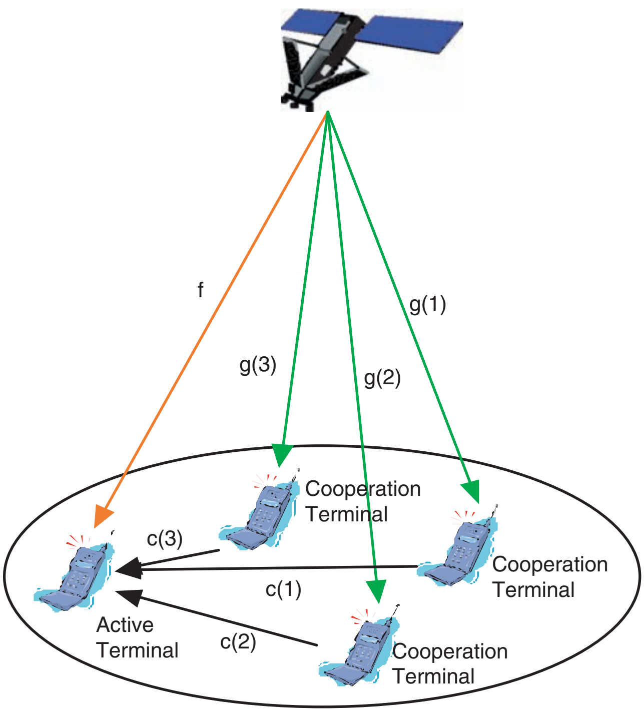

Fig. 1. Downlink satellite cooperation scenario.

Table 1. Main operational parameters.

d_{sat}	36000	[km]	satellite terminal distance
d_{coop}	10	[km]	cooperative terminal
L_{sat}	–205.34	[dB]	satellite terminal path loss
L_{coop}	–118.5	[dB]	cooperative terminal path loss
B_{sat}	36	[MHz]	transpoder bandwidth
P_{sat}	70	[dBW]	satellite power
P_{max}	250	[mW]	cooperative terminal maximum power
G/T_{Rx}	–24	[dB/K]	handheld receiver G/T
T_{sys}	290	[K]	system temperature
F_c	2000	[MHz]	cooperation channel frequency
F_d	11750	[MHz]	downlink channel frequency

signal-to-noise ratios and the link from the satellite to the active terminal (f) is comparable with the links from the satellite to cooperating devices. AF requires minimal processing at the cooperating terminal but it needs a consistent storage capability of the analog received signal. As in [8] we consider the amplification factor A relationship given by

$$A_i^2 = \frac{P_{max}}{P_{sat}|g(i)|^2 + N} \tag{1}$$

where P_{sat} is the satellite downlink power and P_{max} the cooperative terminal maximum power; M is the number of cooperating terminals, $g(i)$ the i-th link pathloss, $N = KT_{sys}B_{sat}$ the noise spectral density at the earth terminals (see Table 1). With this choice we obtain an expression of the resulting C/N on the active terminal.

$$\frac{C}{N} = \gamma f + \sum_{i=1}^{M} \frac{\gamma g_i \gamma c_i}{\gamma g_i + \gamma c_i + 1} \tag{2}$$

By assuming that all of the cooperating terminals have the same characteristics and the cooperative channels are similar we can simplify the previous expression in

$$\frac{C}{N} = \gamma f + M\,\frac{\gamma g \gamma c}{\gamma g + \gamma c + 1} \tag{3}$$

Furthermore we can consider $\gamma f = \gamma g$ so the variables concerning the channel become two (γf and γc).

$$\frac{C}{N} = \gamma f \left(1 + M\,\frac{\gamma c}{1 + \gamma f + \gamma c}\right) \tag{4}$$

The previous expression becomes (*see Appendix B*)

$$\frac{C}{N} = \frac{P_{sat}|f|^2}{N}\left(1 + M\,\frac{A^2|c|^2}{1 + A^2|c|^2}\right) \tag{5}$$

so the signal-to-noise ratio depends on $\gamma_z = f(P_{sat}, A, M, f, c, N)$.

3 Link Budget Consideration

As we can see in (5), AF cooperation can provide some advantages:

- C/N improvement at M growth with all other parameters fixed;
- C/N improvement depending on the choice of A and P_{sat} with M, d_{coop} and F_c fixed (see Fig. 2);
- C/N improvement with variable L_{coop} and M with P_{sat} and A fixed (see Fig. 3);
- P_{sat} decreasing (spot area coverage expansion) at M growth for a fixed C/N;

The target is to try to get a value of the (5) such to guarantee the fruition of the standard DVB-S2 services, a fact that was not realizable using only one mobile. Figure 2 shows the limit of C/N improvement due to choice not to sorpass the P_{max} constraint

$$A^2 \leq \frac{P_{max}}{P_{sat}|f|^2 + N} \tag{6}$$

and the amplification factor range where it is convenient to work to obtain performances gain ($A \approx 110 - 125$ dB). We chose $M = 10$, $d_{coop} = 10$ km and $F_c = 2$ GHz as

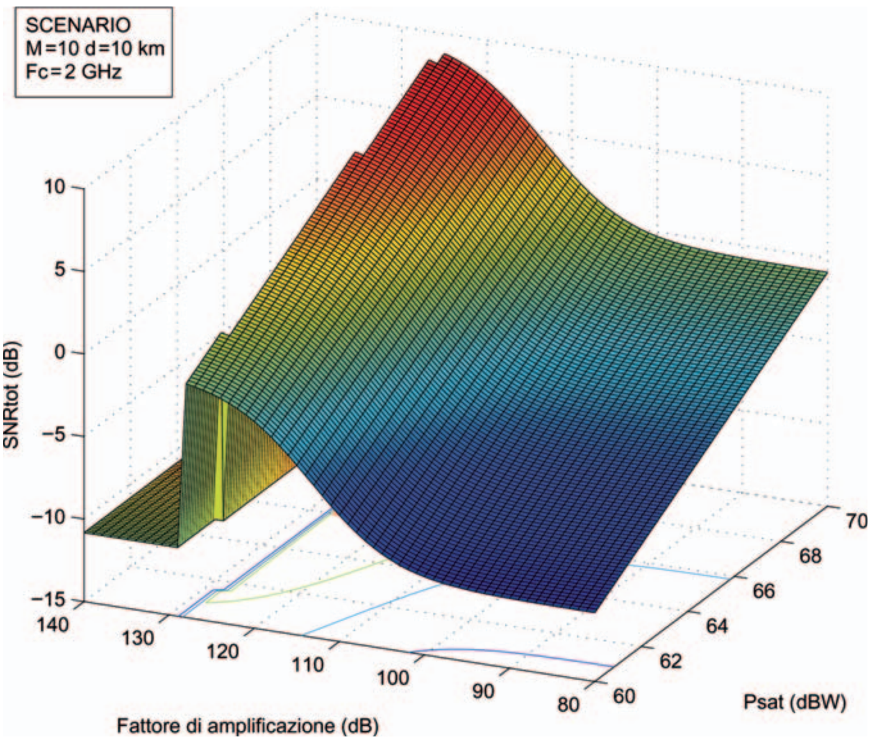

Fig. 2. Receiver SNR vs cooperative terminal amplification factor (A) and satellite tx power (P_{sat}).

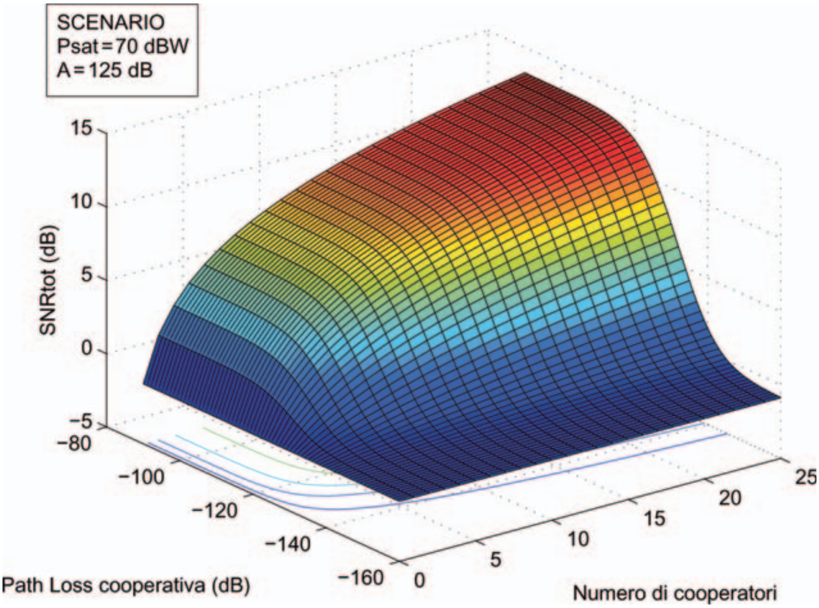

Fig. 3. Receiver SNR vs cooperation link loss (L_{coop}) and number of cooperating terminals (M).

Table 2. Required C/N with 7.2 Mbaud in downlink.

Modulation	useful Mb/s	Eb/No (dB)	C/N (dB)
QPSK 1/2	7.2	1.05	0.08
QPSK 2/3	9.52	1.89	2.13
QPSK 3/4	10.71	2.31	3.07
QPSK 5/6	11.91	2.99	4.21
QPSK 8/9	12.72	3.73	5.23
8-PSK 2/3	14.26	3.65	5.65
8-PSK 3/4	16.04	4.43	6.94
8-PSK 5/6	17.85	5.41	8.38
16-APSK 3/4	21.36	5.49	9.24
16-APSK 4/5	22.79	6.03	10.07
16-APSK 5/6	23.76	6.42	10.63

fixed variables. That amplification factor range depends on the quality of cooperative links and it assume lower values decreasing L_{coop}. This last dependence is better shown in Fig. 3, where the amplification factor is set to its maximum allowable value not violating the P_{max} constraint. In this figure. we can notice the C/N improvement as M and L_{coop} decrease. The required C/N for the transmission modes in DVB-S2 standard [2] are reported in Table 2. As we can see, the AF cooperation strategy with A = 125 dB, P_{sat} = 70 dBW, B_{sat} = 9 MHz gives the chance to use the modulations QPSK, 8-PSK and 16-APSK in the downlink (the required values are under the surface of Fig. 3). So for a given configuration of cooperators (link quality L_{coop} and number M) a specific subset of DVB-S2 compliant modulations can be adopted.

All the results in this section have been derived from theoretical considerations. In particular we considered AWGN satellite channel and the coefficients f and g representing the satellite and cooperation path losses. In the next section a more realistic scenario is considered, with a cluster of satellite terminals with channels modeled with Corazza-Vatalaro model [9,10,11].

4 Cluster Performance

The Corazza-Vatalaro channel is a combination of a Rice and a long-normal factors, with shadowing affecting both direct and diffused components. The p.d.f. of the multiplicative fading coefficient $pcv(r)$ is:

$$pCV(r) = \int_0^{+\infty} \frac{1}{v}\, pRice\left(\frac{r}{v}\right) pLognormal(v)\, dv \tag{7}$$

where r is the received signal envelope and v is the mean power of the directed component. This model has been implemented in Simulink as shown in Fig. 4. The CVchannel block is part of the complete system of Fig. 5 which represents cooperation environment of Fig. 5 under the hypothesis of 10 cooperators. Starting from the left, the model represents the downlink signal available at the satellite whose power is $EIRP_{sat}$. After *CVchannel* and *Free Space Path Loss 205 dB* blocks (top of Fig. 5) the signal is received from the active terminal. The other 10 block chains model the cooperation links. The signals coming from cooperators and active path is combined at the active terminal radio stages (adder block in the model), then demodulated and revealed. It is worth noting that the path-loss value indicated (118 dB) derives from the choice to use a cooperation frequency F_c = 2 GHz and a distance $d_c = 10km$.

It is not considered for the moment the fading effect on the cooperative links, as expected in environments characterized by limited distances (within 10 km) and good visibility among terminals.

The model has been simulated with a time resolution equal to $1/2B_{sat} = 1/14.8MHz$, with B_{sat} being the bandwidth of the modulated QPSK signal (FEC = 1/2) considering an useful data rate of 7.2 Mb/s (Table 2). The resulting BER versus E_b/N_o curves for different configurations have been plotted.

The first graph in Fig. 6 shows the performances of QPSK and 8-PSK modulations with a Corazza-Vatalaro channel characterized by a Rice factor R = 20.

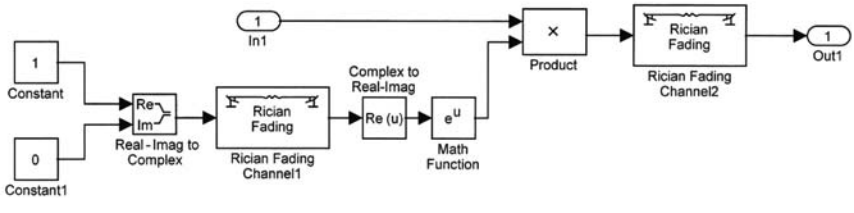

Fig. 4. Satellite CV channel model implementation.

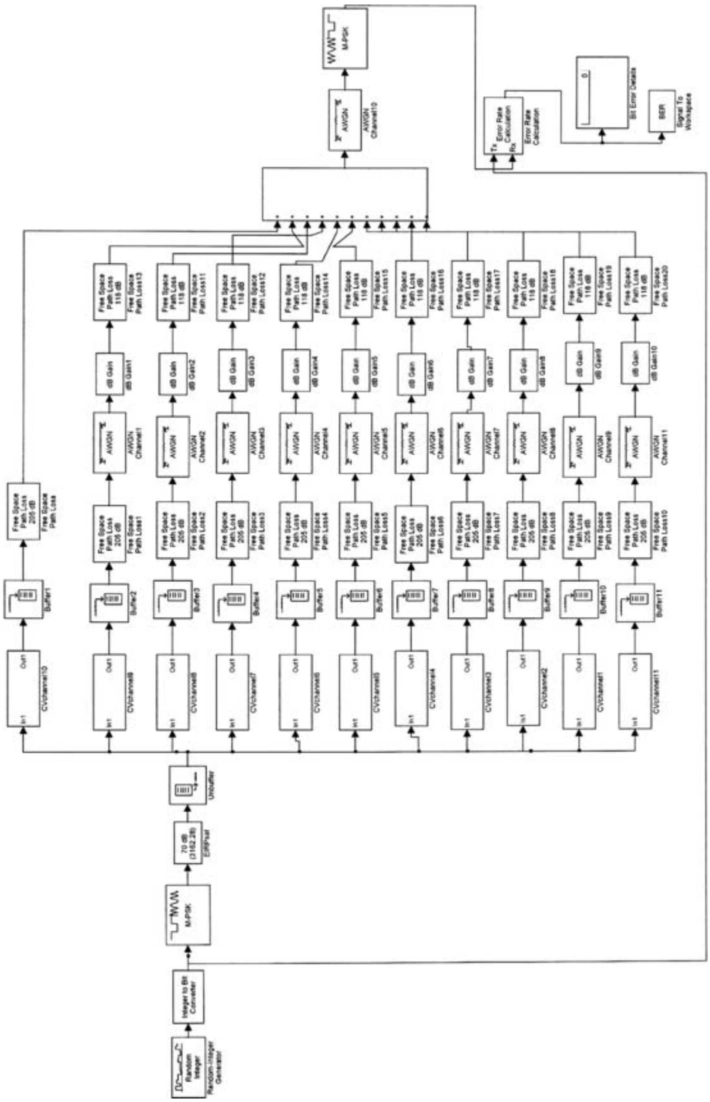

Fig. 5. General block diagram of AF cooperation for DVB-S2 downlink.

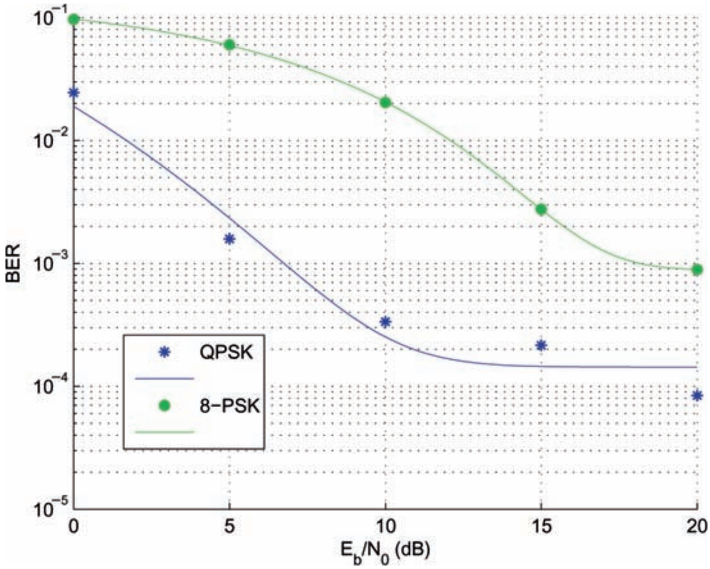

Fig. 6. QPSK and 8PSK with rice factor K = 20 and 10 cooperators.

The performances show an significant improvement, in terms of error probability, in comparison to the case in absence of cooperation for the same modulations (QPSK and 8PSK). QPSK shows a $BER = 10^{-4}$ for $E_b/N_0 = 20dB$, while for the 8PSK gives a $BER = 10^{-3}$ to parity of E_b/N_0. Moreover 8PSK performances become sensibly worse with smaller values of R due to the reduction of the deterministic component of the ricean channel which result in heavy fluctuations of the signal. In the graph of Fig. 7 three conditions of shadowing are considered:

- R = 20 correspondent to very light shadowing values;
- R = 15 representing an intermediate value;
- R = 10 with significant shadowing values.

The curves of Fig. 8 show the advantages deriving from the use of the cooperation AF strategy considering the QPSK modulation. We can see how the performances improve as the number of cooperators increase: on the top of the figure is represented the situation in the absence of relays, then follow the performances with 5, 10 and 15 cooperators. The comparison has been issued choosing a Rice factor $R = 1$; the results ($BER < 10^{-2}$) are acceptable for the channel coding techniques present in the DVB-S2 standard.

By varying the Rice factor R we obtain the results shown in Fig. 9 where QPSK performances with heavy shadowing ($R = 0.6$), medium shadowing ($R = 1$) and light shadowing ($R = 4$) are compared. For R = 4 the performances are close to the target ($BER = 10^{-4}$), while for $R = 0.6$ the BER values are higher then target resulting unacceptable for DVB-S2.

It is worth noting that in these simulations all the handset share the same Rice factor R, modeling the situation where the consumers cooperators all work under

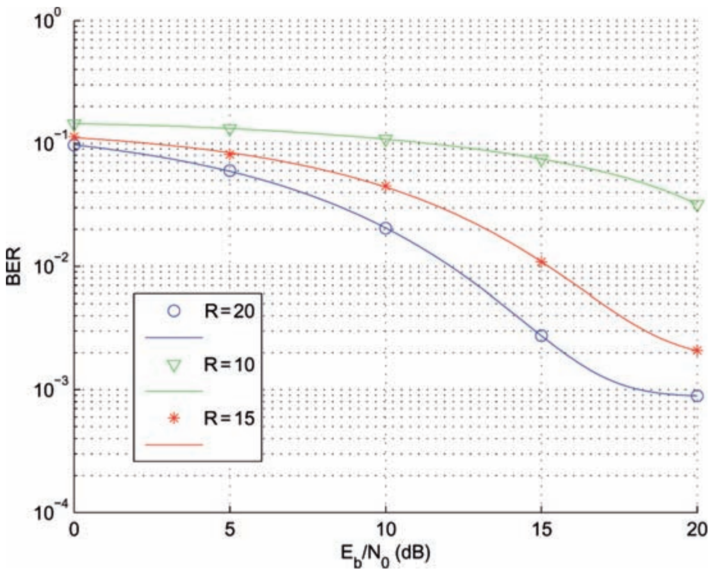

Fig. 7. 8PSK with variable R = 10;15;20 and 10 cooperators.

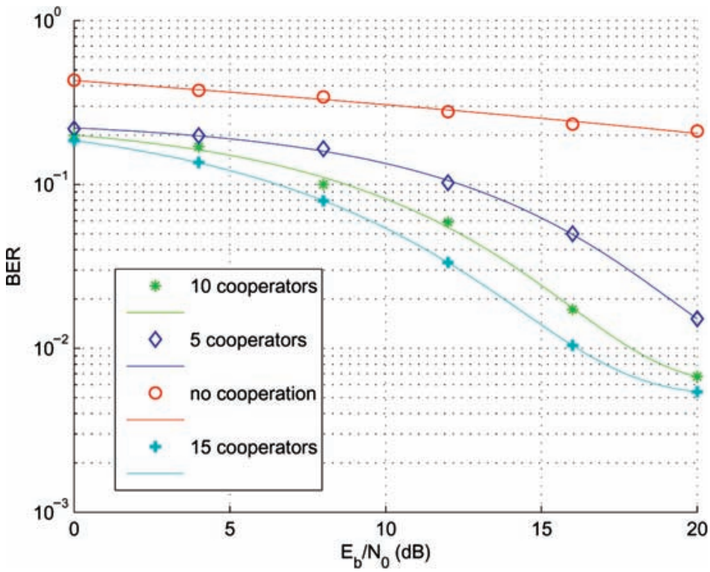

Fig. 8. QPSK with cooperator number variable M = 0;5;10;15 with R = 1.

homogeneous operational conditions. By considering a less critical situation, where only a subset of cooperating terminals are subject to heavy shadowing, we can see (Fig. 10) that the performances improve. Figure 10 shows the BER in the case of 50% of the handset are in heavy shadowing (R = 0.6) while the remaining ones have R = 1.

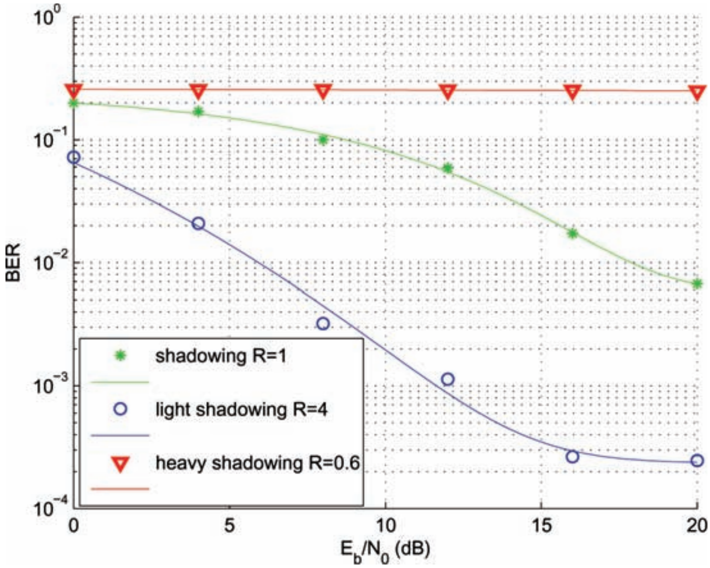

Fig. 9. QPSK for variable R = 0.6;1;4 and 10 cooperators.

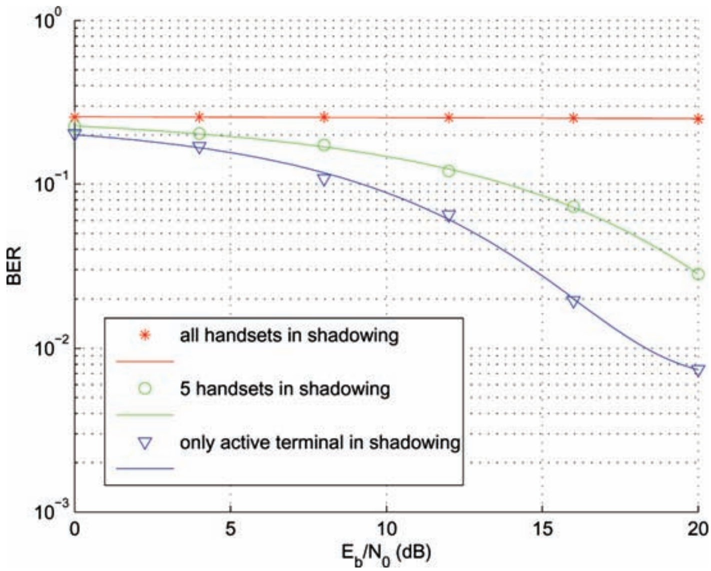

Fig. 10. QPSK varying handset number in shadowing for R = 0.6.

5 Conclusions

This paper shows a possible solution to the problem of the extension to the mobility (direct receipt on mobile terminals, equipped with non directive antennas) of a satellite transmission DVB-S2. The idea is to build a cooperation among a set of mobile terminals, in a way that the signal received by each single device is the result of the composition of more replicas of the same signal sent by other cooperating devices.

The choice of the adopted link cooperation method (Amplify and Forward) has been suggested by the satellite operational context (Fig. 1), characterized by unbalanced link strengths and limited complexity available at cooperators.

Link budget analysis shows that by choosing feasible system parameters (satellite spot power, co-operation amplification factor, number of co-operating terminals, terminal power dedicated to co-operation) we obtain signal-to-noise ratios compatible with DVB-S down-link profiles for up to 16-APSK constellations.

Under a more realistic scenario, where all the cooperators are independently faded accordingly to the Corazza-Vatalaro channel model, high order modulations are still possible in presence of favorable propagation conditions.

Link cooperation enables the reception of DVB-S2 services from handheld terminals when a cluster of cooperating users is present. This is a common context when professional users are involved (emergency rescue teams, tactical scenarios).

In the case of personal communications, the link cooperation technique may be offered as an option to overcome reception limitation, so the single subscriber has the possibility to choose if to participate to the cluster or not. This model allows the user to retain the control over the power resources of its terminal.

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