SPACE WEATHER AND SATELLITE COMMUNICATIONS: AN USEFUL SYNERGY BETWEEN GEOPHYSICISTS AND ENGINEERS

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ABSTRACT

This work discusses space weather effects on satellite communications. After presenting trends in mobile satellite communications and signal processing, impacts of space weather are analysed. The article also points out that a partnership between geophysicists and engineers is useful for both physical analysis and management of space weather effects, such as scintillations in satellite/GPS systems; single-event upsets in satellite circuitry, and distorsions on signals due to geomagnetic storms.

INTRODUCTION: TRENDS IN MOBILE COMMUNICATIONS [Eva99]

The Universal Mobile Telecommunication System (UMTS) norm [1] is the major current trend in mobile communications. This norm aims at establishing a global mobile system, wherein any terminal may communicate with any other terminal. The terminals may be located anywhere on the Earth, and the terminals may also be mobile or non-mobile. The deployment of UMTS requires interconnection of several different local telecommunication systems, in order to provide the link between the two terminals. Of course, satellite communications play an important role for UMTS, since they provide cost-effective international links. Moreover, several positioning/navigation systems are based on satellite constellations, such as the GPS and the European Galileo [2]. It should be also pointed out that, in order to cope with the scarcity of transmitting frequencies, the European comission has recently launched a plan for assessing the viability of multimedia and INTERNET data transmission above 30 GHz, by means of satellite links [3].

Three major characteristics of the UMTS are discussed in the following.

(C1) The demand for increasing transmission rates presents challenges to bandwith management and transceiver processing [1].

(C2) The communication channel is a time-variant system difficult to characterize. In fact, temporal variations may be predicted with limited accuracy, and models are quite dependent on both the spatial and time scale [1]. As a consequence, synchronization between the two communicating terminals is quite problematic, which may be explained by deep fades taking place in the links between mobile users and base stations (either terrestrial or satellite).

(C3) The characterization of mobile channels associated with telecommunication between two aircrafts in flight, or between aircraft in flight and satellites, or even between two satellites, may be considered one of the big challenges for UMTS implementation [4].

Signal processing techniques are important tools applied to cope with (C1)-(C4), particularly the theories applied for the following research topics.

(R1) Analysis of non-stationary signals or time-variant (non)linear systems. In fact, the mobile channel model is well modeled as a time-variant system [5], which is also nonlinear for the case of satellite communications.

(R2) Real-time prediction of non-stationary signals. The main goal is to enable the forecasting of time-variations in the mobile channel, so that the UMTS manager may carry out actions in advance for ensuring system performance and synchronization. Such an idea is the basic principle underlying the concept of "adaptive transmission" [4,6].

(R3) Equalization [7], which corresponds to the digital filtering of the incoming signal at the receiver, in order to overcome impairments imposed by the communication channel on the transmitted signal.

EFFECTS OF SPACE WEATHER ON UMTS AND CURRENT SATELLITE COMMUNICATIONS

The effects of space weather should be considered in the context of the discussions of the previous section. References [8-11] provide a good review in the general effects, as well as concrete examples of the practical interest in the management of space weather influence on technological systems. Related work is also developed in references [12,13], which are excellent reviews focused on satellite communications.

Since geophysical phenomena connected to solar flares are mainly non-stationary [8], space weather effects introduce a new degree of time-variability in signals and systems associated with mobile telecommunications. Of course, according to (C2)-(C3), this not only makes system synchronization still more difficult, but also disturbs aeronautical communications in a special way. The lack of synchronization means that, according to (C1), the huge information exchange rate through the satellite is disrupted, thus blocking communication between terminals of the UMTS. A worst-case influence would be the case of disruptions on spacecraft/satellite telemetry, tracking and control, which could lead to orbit perturbations.

The effects discussed above would be even more serious in Latin America, due to the unusual behavior of the geomagnetic field above some particular areas. For example, in the case of Southeastern part, the regions under the South Atlantic Anomaly (SAA), as well as the equatorial regions, which are subject to the effects associated with the Equatorial anomaly (EA) [14] and with the equatorial electron jet. Notice that ionospheric bubbles impose additional geomagnetic effects on the SAA and EA. It should be stressed that several economic centers of the continent (Buenos Aires, Montevideo, Assuncion, Rio de Janeiro, São Paulo) are located under the SAA. Besides, mineral exploration in the Amazon region (petroleum in Venezuela, mines in Peru) and telemetry of rocket launching basis in Brazil/Guyana (ESA) are also subject to ionospheric bubbles effects. Finally, it should be noticed [15] that almost 70-80% of satellite circuitry failures take place as the satellite flies over the SAA.

On the other hand, the time-variability of space weather signals and systems is a common characteristic with respect of mobile communication signals and systems. As a consequence, one could propose that the theories and methods used in topics (R1)-(R2) would be also useful for space weather research.

In the following, some particular case studies are presented to illustrate the current research and trends in Latin America, particularly in Brazil.

SCINTILLATIONS ON SATELLITE AND GPS SYSTEMS [16]

The INPE (National Space Research Center), Brazil, along with Cornell University, have set up several GPS receivers in the Brazilian territory, in order to evaluate the fluctuations of signal amplitude due to scintillations. In fact, such phenomena disturb seriously the positioning of vessels performing deepwater petroleum exploration [17], as well as deep fades and distortions on other code-division multiple acess (CDMA) systems, such as mobile phones and aeronautical communications or navigation [18]. Although all these effects are connected to ionospheric bubbles, experiments [19] carried out in the SAA pointed out also that scintillations may strongly impair commercial satellite communications around 3-10 GHz, especially during the evening.

At the same time, using the same data provided by this network of GPS receivers, it is possible to carry out determination of the Total Electronic Content (TEC) and analyze the behavior of ionosphere during geomagnetic storms in SAA. Current research involves not only these calculations, but also the statistical characterization of fades associated with scintillations in order to mitigate distorsions on receivers.

SINGLE-EVENT UPSETS IN SATELLITE CIRCUITRY

Single-event upset (SEU) is an effect associated with high-energy protons flow towards the Earth, which may damage circuits, since the miniaturized VLSI systems are vulnerable to solar particle collision. This is particularly important for Low Earth Orbit (LEO) satellites, which play an important role in the current satellite branch of UMTS. The particle bombardement of memory units may impair software operation due to physical damage or due to the corruption of stored data. For example, the value of one bit located at a place in the memory unit may be changed. This event is called "bit upset" [15]. As a consequence, data corruption at the floating-point unit and in the registers, as well as unexpected operations at the arithmetic and logic units may be observed in microprocessors on-board telecommunication satellites [20].

In fact, according to [15], at least 400 bit upsets per day are expected during a high-solar activity period such as 2000-2003. Of course, this may lead to difficult problems considering that adaptive filters are implemented in microprocessors. Notice that adaptive filters are the basic unities for the implementation of equalizers, and for portions of software radios and adaptive transmission techniques. The authors have already evaluated some of these problems in the context of classical [21] and nonlinear [22] equalizers, and the main conclusion is that SEU lead to poor system performance, since the equalizer can not assure a reasonable signal recovery.

Current research involves consequences of SEU on UMTS, software radio and adaptive transmission schemes. Physical models of SEU effects on microprocessors are needed for analysing system effects, thus requiring interaction with geophysicists.

PREDICTION OF GEOMAGNETIC INDEXES AND MITIGATION OF DISTORTIONS DUE TO SOLAR FLARES

Ionospheric blackout is a big challenge for engineers, since this phenomenum leads to two major problems, which are closely related to the potential effects of geomagnetic storms on UMTS: extremely low signal-to-noise ratio and complete loss of system synchronization. These problems make it almost impossible to employ classical equalization techniques, thus requiring tools specially designed for coping with "almost zero" input power to the equalizer.

Current research involves the study of the magnestopheric model proposed in [23], which is closely related to deconvolution techniques. Since this model is an application of linear prediction theory, the authors consider that the work over time may also lead to new insights on the forecast of geomagnetic indexes. Insights on the use of signal processing for the analysis of geomagnetic-storm time series are also discussed in [24].

CONCLUSION

Whereas geophysicists concentrate their efforts on the comprehension and modeling of the physical phenomena connected to solar flares, satellite engineers devote their energy to mitigating distortions due to the same solar flares [25,26]. Since these distortions could be considered as consequences of the same physical phenomena studied by geophysicists, then it is straightforward to state that the distortions for engineers are exactly the useful information for geophysicists. As a consequence, an interesting partnership could be established, where insights on the physical phenomena would help engineers to build up models in real-time and to propose real-time mitigation techniques, in order to cope with telecommunication impairments. On the other hand, engineers might be useful for space weather research, by providing real-time modeling and forecasting methods [27] to geophysicists. Particularly, signal processing tools associated with analysis and prediction of non-stationary signals seem to be an useful framework for both fields.

The case studies presented in this paper point out the usefulness of the strategy proposed in the last paragraph. At the same time, the main challange for carrying out the common research seems to be removing boundaries, in order to establish communication between the two research communities, as well as multidisciplinary education initiatives, for example, see [28].

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