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Satellite communication prototype based on SDR

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Extended abstract

The railways industry is at the moment looking for innovations and solutions supporting their core business and increasing the capacity of the rail system. One aspect is the development of a new communication system that improves shortcomings at the European Train Control System (ETCS) with an adaptable multi-bearer train-to-ground communications system. The idea is to increase the capacity and improve the availability of the communication system by using multiple bearers or providers like, 5G, LTE, WiFi or SatCom. Testing these solutions can become cumbersome since multiple networks must be set up and especially in the SatCom case there are multiple options for bearers. SDR offers a solution for this: the bearer can be implemented in

software and adapted if needed to model other technologies. We present here a prototype design that modules a satellite channel and can be used to model a satellite bearer.

Introduction

A recent study on how Satellite Communication (SatCom) systems can satisfy Future Railways Communication System (FRCMS) requirements revealed that none of the current system is able to fulfil all requirements [1]. This implies that either SatCom systems can only be used for certain applications or that the requirements must be loosening. In other words, it must be decided by an application if it excludes SatCom, if the requirements are not met, which can mean a loss of service if terrestrial infrastructure is not available, or it includes SatCom which could mean limited service. A system considering SatCom and terrestrial systems must be flexible to allow the integration of different SatCom systems. In this way the train providers can select a suitable SatCom solution for their demands.

The main blocking factor according to the study is the voice application with requirements on availability and latency that cannot be fulfilled by SatCom. Focusing on signalling use cases SatCom systems can match the criteria and are a fitting solution.

The study further showed that a theoretical MEO/C-Band system would fit the best which shows that future SatCom systems will probably deal better with the requirements. This includes LEO mega-constellations but also upcoming MEO and GEO solutions, again dependent on the applications demands.

The added value by including a SatCom system highly depends on the scenario, e.g. in urban scenario there is already coverage provided by terrestrial systems and due to shadowing SatCom might be unavailable. On the other hand SatCom fits well the high speed line and the regional line scenario due to their availability and low CAPEX, see also [1].

The SatCom prototype developed during the X2Rail-1 project will model a satellite system by the use of software defined radio (SDR). The prototype can be included as a bearer for field tests and advantages, disadvantages, potential gains or losses can be evaluated in tests. In principle, FRMCS shall be independent from radio access technology providers. Since most commercial SatCom systems are proprietary and do not follow a common standard, the easiest way for testing is a flexible test bed that can be adapted to different systems models. The SDR approach offers this flexibility and could even be enhanced to model future SatCom systems that are planned for the next decades.

Especially for the urban area, it is expected that the requirements on the future communications system can be addressed entirely by terrestrial technologies since they are highly available and the coverage of SatCom suffers due to shadowing caused by buildings [1]. The biggest advantage of SatCom is the coverage area which can save a lot of costs, especially in rural areas where additional terrestrial infrastructure would be needed. Hence, SatCom is considered for the regional/freight line and for the mainline/high-speed line demonstrators.

Architecture

A multi-bearer system is assumed that uses the adaptable communication system (ACS) developed in the X2Rail-1 project. The system can in principle use multiple bearers like 5G, LTE, WiFi or SatCom to connect to the backbone. The ACS routes in a transparent way traffic through the bearers satisfying QoS parameters of the dedicated applications. Focusing on the SatCom bearer Figure, 1 shows a SatCom setup for railways as it was proposed by [1]. The setup fits also the approach followed in X2Rail-1. SatCom systems usually consist of a ground segment, i.e. the terrestrial backbone, the space segment (satellites) and the user segment. The transceiver unit of the user segment is called terminal. The link from gateway to terminal is referred as forward link, the one from terminal to gateway as return link, both having their own characteristics and technologies used and can be investigated separately. Hence, we divided the prototype in two parts that can be used to optimally investigate the SatCom bearer within the X2Rail-1 demonstrators.

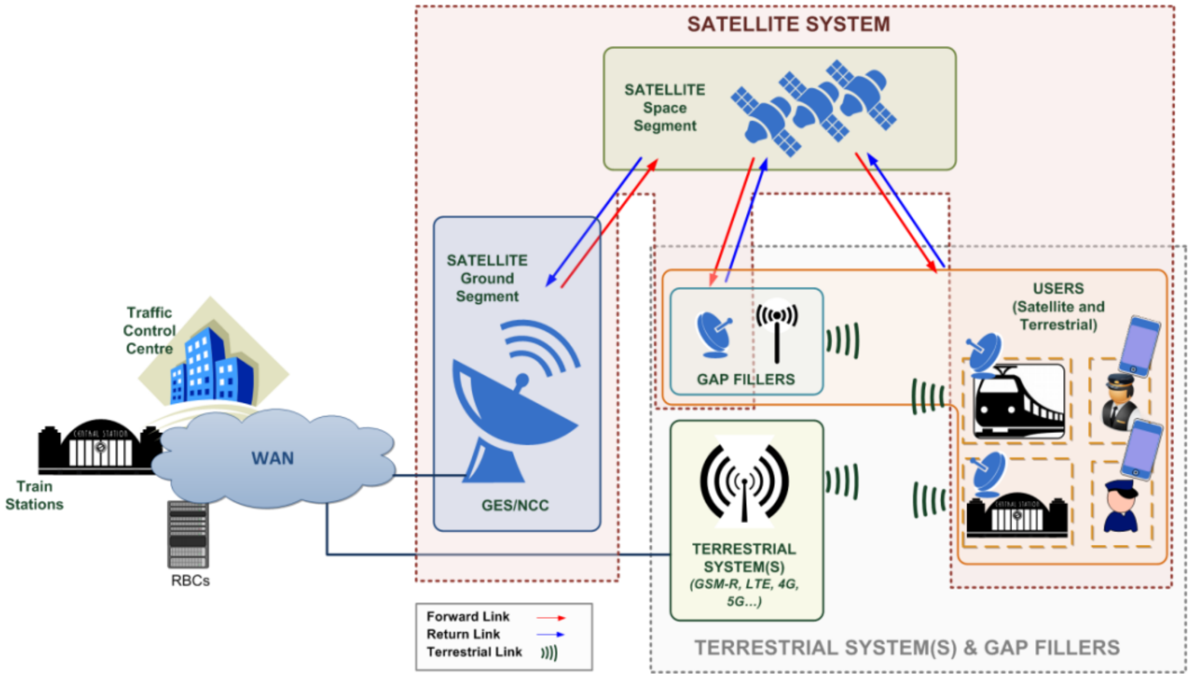

Figure 1: SatCom for railway [1]

Prototype

For our prototype we focus on the return link in which multiple terminals (up to tens of thousands) are connected to the system (via one or more transparent satellite(s)) and the resource allocation is not as simple as in the forward link. Differently from the forward link, each active terminal sends a request for data transmission and waits for its allocation in the available resources (time and frequency). Due to the large propagation delay – in the order of 250ms for typical satellite links – such a procedure may become particularly inefficient for small data transmissions. Efficient solutions targeting messaging systems have been lately developed, relying on advanced random access (RA) protocols. Positioning and safety related railway messages are included in the messaging systems for which advanced RA schemes are developed, making them an ideal solution for future railway communication standards. Therefore in our prototype we consider a RA protocol where multiple uncoordinated transmitters share the available band.

Random access ALOHA-like [2] protocols have been originally proposed for the satellite domain already from the early 70's. The far distance among terminals served by a common satellite or satellite constellation prevents the use of sophisticated carrier sensing techniques.

In the recent past several advanced random access schemes have been proposed [3]. The recent enhancements have shown that RA is able to become efficient in terms of spectral efficiency and appealing in terms of target packet successful probability (probability of correctly decoding a terminal), which have been the key drawbacks in the seminal protocols ALOHA and slotted ALOHA [4]. Among the many narrowband solutions proposed in the last years, two main classes of protocols can be identified. On the one hand, slot-synchronous schemes, derived from the slotted ALOHA protocol can be found in recent literature. On the other hand, asynchronous schemes, derived from ALOHA have been proposed as well. Due to their simplified terminal architecture (no slot synchronization is required) and therefore reduced cost, asynchronous random access protocols shall be a preferred solution.

Contention Resolution ALOHA (CRA) [5], makes the use of two key ingredients to improve the spectral efficiency: the use of proactive replication of packets at the physical layer and the use of successive interference cancellation at the receiver side. User terminals benefit in terms of complexity, since no common clock to synchronize is needed anymore. The terminals transmit their replicas within a maximum delay (called virtual frame) whose duration is known also at the receiver. Time slots, synchronized to the transmitters' own internal clocks (and therefore asynchronous among different users and with receiver) can be adopted so to simplify the signalling of the replicas location within the header. At the receiver side, the receiver will need to operate with a sliding window. The receiver window duration shall exceed the virtual frame duration, while the window shift shall be small enough to guarantee that no decodable replica is lost after the moving of the window forward in time. The successive interference cancellation (SIC) procedure iterates within the receiver's decoding window, and iteratively cleans up the received signal every time a replica is correctly decoded. The successive interference cancellation in CRA is also described with the example of Figure 3.

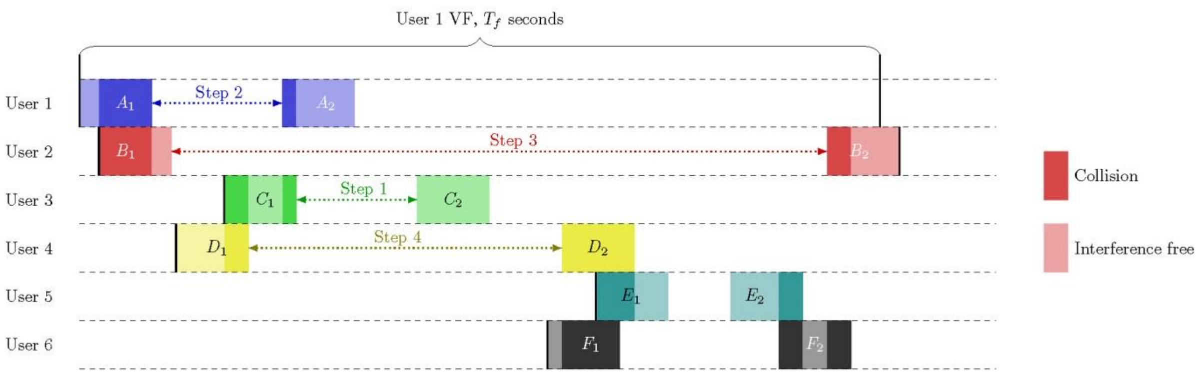

Figure 3: SIC Procedure of CRA

The receiver starts seeking for replicas that can be correctly decoded. The first one to be found is replica C2, which is free from interference. Interference cancellation can be applied once the location of C1 is retrieved upon successful decoding of the packet content, leading to a decrease in the interference level perceived by replicas D1 and A2. In the second step replica A2 is correctly decoded and SIC is applied on both A2 and A1. Iterating over all detected replicas yields the successful retrieval of all data packets of users 1 to 4. User 5 and 6 may be also decoded, assuming that the PHY error correcting code used to protect the replicas is strong enough. Extensive studies have investigated a reasonably good waveform and identified the configuration using two replicas, QPSK modulation Turbo Code rate 1/3 as very good candidate [6].

The presented scheme can be extended to be adopted also with multiple channels. The key difference is that terminals are required to be able to operate on different frequencies. A full CRA protocol implementation will be implemented in SDR, including all estimation, encoding and decoding blocks. Random Access protocols in general, feature high flexibility in terms of population size, mobility, terminals inhomogeneous requirements. The presented protocol is able to achieve high efficiency with low terminal complexity (and therefore cost) so to be very appealing for the industry as well.

In Figure 4 the high level architecture of the testbed is presented. At transmitter (Tx) side the aggregate traffic of the multiple transmitters is generated by a single hardware unit (PC). The full transmitter chain including, data generation, encapsulation and header generation, encoding, physical layer preambles and pilots (for detection and channel estimation) are added. The signal is then oversampled and pulse shaped. White Gaussian noise, typical channel model for satellite channels is added. The generated signal is passed to the SDR which converts the digital signal into analogue domain and transmits it. At the receiver side, the SDR is responsible for the analogue to digital conversion. After matched filtering, packet detection is performed.

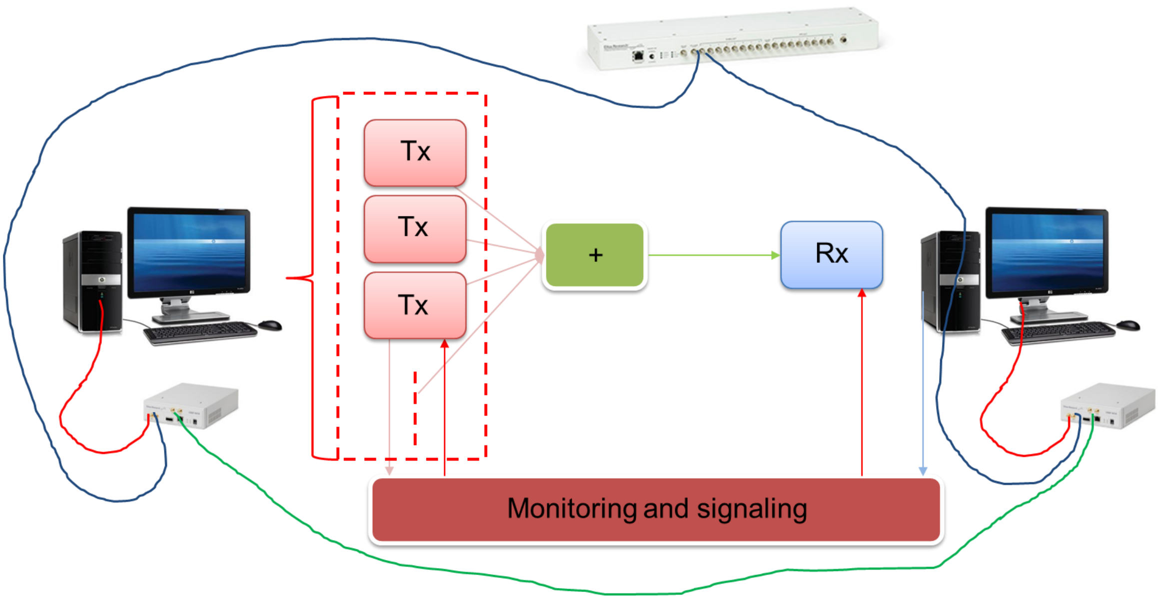

Figure 4: Prototype return link

For all candidate replicas identified, detailed channel estimation (including timing, frequency and phase offset estimation) is performed. The channel decoder counteracts the channel noise and finally, upon correct decoding, the data transmitted is retrieved at the receiver. Once this is achieved, successive interference cancellation on the replicas of the decoded packet takes place. Both the transmitter and receiver SDR are connected to a GPS-based external reference clock that guarantees high stability of the oscillators for timing and frequency offsets.

Conclusion

We presented a SDR based prototype for SatCom that can be used for evaluation and lab-test. It is based on a modern RA scheme focusing on signalling application.

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