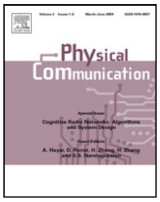
Physical Communication 30 (2018) 167–178

Contents lists available at ScienceDirect

Physical Communication

journal homepage: www.elsevier.com/locate/phycom



Full length article

A software defined radio based data link design for VHF band wireless sensor networks

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ARTICLE INFO

Article history:
Received 27 November 2017
Received in revised form 14 July 2018
Accepted 21 August 2018
Available online xxxx

Keywords:
Channel modeling
Data link design
Tactical communications
Sensor networks
Software defined radio

ABSTRACT

In this paper, we present an overall data link design for a tactical wireless sensor network operating at VHF band considering software defined radio (SDR) approach. An empirical channel modeling for the target environment is developed, and the large and small scale statistics of the wireless channel are obtained. Then, the physical layer properties including modulation, channel coding, frequency hopping are designed according to the power and bandwidth efficiency requirements. Additionally, the medium access control (MAC) and automatic repeat request (ARQ) protocols are designed and the complete end-to-end system is tested in the field using the SDR platform. The measurement results are promising for the proposed datalink of the VHF wireless sensor networks operating in the dense hilly environments.

1. Introduction

Tactical communication systems are designed to provide secure and reliable mission-critical communication capabilities for military. In recent years, wireless sensors are being increasingly used for tactical communications [1]. Especially, designing a reliable data link that collects the data from wireless sensors in the harsh channel environments and conveys them to center node is critical. Prior to designing of a data link for such wireless sensor networks, the channel propagation needs to be modeled by performing the measurement in the field [1,2]. Due to physical phenomena like reflection, refraction, diffraction, and scattering the wireless signal that is traversed the path from a transmitter to a receiver faces distortion or impairments in various ways [1–3].

The multipath components (MPCs) with different phases, delays, and attenuations can be added at the receiver side constructively or destructively, which leads to the fading phenomenon [4,5]. The phases of the MPCs depend on the position of the transmitter, the receiver and the surrounding objects, and the amplitude of the total signal changes with time [6,7]. Small scale fading statistics are obtained using this aggregated MPCs. The large scale fading statistics consist of path loss of the signal as a function of distance and shadowing variance. This implies that the signal propagation over wireless channel varies according to the environment, therefore the aim of the channel modeling is to characterize the effects of the channel environment on the communications signal [5–7].

In the literature, the software defined radio (SDR) application on VHF band is also investigated in [8–11]. The developed applications are run at different carrier frequencies and modulation schemes. However, the scenario proposed in our paper is not studied in the aforementioned papers.

The contributions of this study are two folds: (1) empirical channel propagation modeling of VHF band (144–147 MHz) in the dense hilly environment, (2) SDR implementations of the PHY and MAC layers for the data link of tactical wireless sensor networks.

In this paper, we consider a tactical wireless sensor network operating at VHF 144–147 MHz band. The studies on VHF channel propagation modeling mostly cover the urban as well as the rural and forested environments [12–17]. However, to the best of our knowledge, very few publications are available in the literature that discuss the issue of channel modeling at the VHF band in hilly, irregular terrain with fixed terminals. For instance, VHF propagation measurement at a frequency of 110.6 MHz at low altitude over hilly and forested terrain have been performed to develop a computer-based propagation model which could predict path loss by giving the terrain profile between the transmitter and receiver [12]. But, the propagation of waves in the hilly and forested area faces different propagation mechanisms than only hilly terrain. Additionally, taking measurement at different altitude have impacts on the propagation characteristics of signal. Moreover, the measurement that have been carried out at 210 MHz frequency in the city and the outskirts of Bern, which is one of the hilly regions of Switzerland, in order to find the multipath delay spread of terrains [18]. Related works in the field of empirical and ray-tracing based channel modeling for urban, rural and suburban regions and indoor can be referred to [19–27]. However,

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https://doi.org/10.1016/j.phycom.2018.08.007
1874-4907/

none of these studies coincide with our work geographically and the operating frequency band. In [28], ray-tracing based channel modeling for VHF band (145 MHz) is conducted using Wireless Insite software tools. Additionally, there is not any study in the literature on channel modeling of 145 MHz frequency at hilly and irregular terrain. Hence, modeling of the channel environment for wireless sensor networks operating at VHF frequency band plays an important role in developing tactical wireless sensor networks.

Large and small scale channel statistics can be used for the tactical communications system design [18,29–31]. Based on the channel characteristics, modulation and channel coding schemes of the system are determined. Note that the fundamental requirements of tactical wireless sensor networks are power efficiency, minimization of out-of-band emission, i.e., spectral efficiency, and bit error rate performance to achieve target desired quality of service (QoS) as well as low receiver complexity [32]. In this study, the communication environment is selected as a hilly and mountainous environment where remarkable path loss, shadowing effects and large delay are experienced. As the modulation and channel coding scheme, continuous phase modulation (CPM) and low density parity check (LDPC) channel coding combination is selected. The choice of proper combination of LDPC and CPM is crucial to satisfy the target tactical requirements of spectral efficiency, power efficiency and complexity of the system. Therefore, this specific combination is chosen as a suitable tradeoff among these three criteria. Besides the CPM–LDPC combination, frequency hopping (FH) is also applied to the design in order to reject interference from external sources.

In order to show the performance of the proposed data link for the VHF tactical wireless sensor networks, the system is implemented in the SDR platform and the measurements are performed in the field. The overall communication system is implemented in an SDR platform, which is NI USRP 2920 device. In the field tests, the tactical communication system consists of a center node and wireless sensors are considered. The sensors collect data from the environment and send the data to the center node through the designed data link. In order to allow packet based multiple access, time division multiple access (TDMA) based medium access control (MAC) protocol which controls the packet delivery using automatic repeat request (ARQ) is designed.

The paper is organized as follows: In Section 2, empirical channel modeling of VHF tactical wireless sensor networks is presented. In Section 3, the design of physical and MAC layers are provided. This includes LabView design for ARQ and MAC layer protocols. This is followed by the demonstration of the field test results of overall network using NI 2920 devices. Finally, the conclusion remarks are presented in Section 4.

2. Empirical channel propagation modeling

The common methodology for designing a wireless system (i.e. data link in our case) for a given frequency band operating at target channel environment is as follows. Initially, the channel propagation modeling for the given frequency band is performed in order to understand the statistical characteristics of radio channel for the desired operating environment. Once the statistical propagation parameters are obtained, then these parameters are utilized for the selection of transmission and reception techniques (modulation, coding, etc.) and algorithms at transmitter and receiver side. Therefore, in this study, we first aimed to obtain the statistical parameters of target channel environment, which is presented in this section.

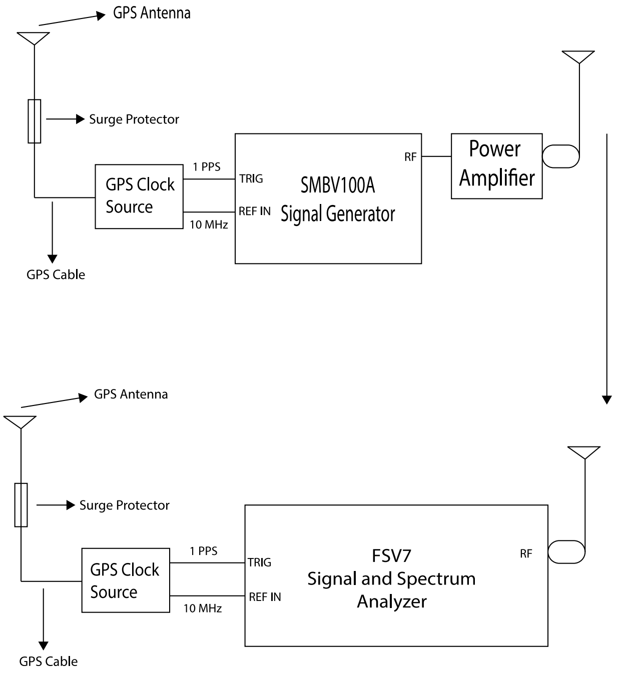

Fig. 1. Channel measurement setup.

Table 1
Channel measurement setup equipments.

Equipment	Usage
Rohde & Schwarz SMBV100A	Vector signal generator
Rohde & Schwarz FSV7	Signal and spectrum analyzer
Rohde & Schwarz FSV7 B-22	Preamplifier
Mini Circuits LZY-1+	50 W (47 dBm) RF PA
SpectraCom EC1S GPS clock	Reference GPS clock
RFS dipole antenna	145 MHz TX/RX antenna

2.1. Channel measurement setup and environment

VHF tactical wireless networks are mainly deployed in harsh environments such as valleys and dense rocky hills and mountains. Therefore, we have selected such region (Inozu Valley) in Ankara, Turkey for the channel measurements. In our application, VHF tactical wireless sensor networks require long-range communications (on the order of kilometers). Hence, we have selected a time-domain channel modeling method, which is preferred for the long-range channel modeling [1]. The channel measurement setup for this method is shown in Fig. 1. In the measurement setup, Rohde & Schwarz SMBV100A and FSV7 equipments are considered as transmitter and receiver, respectively [33,34]. The RF power amplifier of 50 W (47 dBm) is used at the transmitter side in order to increase the transmission range. The transmitter and receiver need to be synchronized in frequency, phase and time for conducting the channel propagation measurements. The GPS clock reference is used to achieve synchronization between devices in time and frequency. For this purpose, SpectraCom EC1S GPS Clock Reference is employed which produces 10 MHz reference signal and 1 PPS (one pulse per second) signals from the received GPS signals. The generator SMBV100A transmits signal when the device is triggered by the 1 PPS signal from TRIG inputs, and at the same time signal analyzer FSV7 starts to sample when TRIG gets the trigger signal. As a result, both devices start to transmit and receive synchronously. The block diagram of the measurement setup and the list of the used equipments are shown in Fig. 1 and Table 1, respectively.

The transmitter is located at the highest point of the measurement environment which has altitude of approximately 1590 m.