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Accurate Ranging/Localization Technique using IR-UWB for Smart Fiber-Wireless In-House Networks

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Abstract *The use of a RoF scheme for localization purposes of mobile stations for in-house networks is presented. Using impulse radio UWB over SMF and time-of-arrival localization method, mobile stations can be localized within centimeters accuracy.*

Introduction

Our information society today is marked by an increasing need for mobility and permanent accessibility. At the same time, the desire for ever higher data transfer rates is also increasing due to various bandwidth hungry applications such as HD video movies, on-line gaming, etc. Mobile data access with the highest capacity and the best quality of service using a single fiber-radio infrastructure forms the ultimate target of wireless communication networks. Recently, research activities on broadband wireless systems have focused on the use of ultra wide-band (3.1-10.6 GHz) and higher frequencies band such as 60 GHz and beyond. For such transmissions, free-space propagation loss is high and therefore high-gain directional antennas are required. The use of such antennas becomes difficult to provide mobile coverage when compared to common omni-directional antennas. However, an omni-directional antenna is not power efficient. In this paper, we describe a smart fiber-wireless (FiWi) in-house network that integrates wireline and power-efficient wireless technologies. This integrated network features an optical fiber network backbone between a central control unit (residential gateway=RG) and all rooms with fixed terminals and radio access points (RAPs) for wireless transmission. This smart in-house/building network performs efficient utilization of wireless power by using a beam steering scheme. For beam steering, the location of a mobile station (MS) in a room must be determined precisely in order for RG and RAP to make a narrow beam footprint around MS.

Smart FiWi In-House Networks

Fig. 1 shows an example of FiWi in-house networks employing smart radio beam-steering. The network is based on an adaptively routed optical fiber backbone, running from a RG, which feeds transparently RAPs with radio signals[1]. The fiber backbone uses RoF technologies to keep RAPs simple and is radio transparent. Each RAP can perform O-E and E-O conversion and multi-radio protocols at 2.4, 5, and 60 GHz.

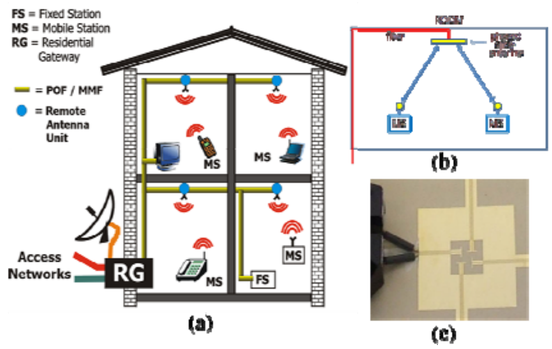


Fig. 1: (a) FiWi in-house networks, (b) smart radio beam steering, (c) 2x2 phased-array antenna.

For pico-cell RoF systems, RAPs do not use an omni-directional concept, but transmit confined radio beams directed towards mobile terminals in the room by means of adaptive radio beam steering. This beam steering concepts have two advantages. First, this concept allows us to use the radiated power more efficiently at improved communication quality. Second, the well-directed radio beam can reduce mutual interference between mobile terminals, hence increasing the link performance at reduced power consumption and electromagnetic human exposure. Control of the direction of the radio beam is done centrally at RG which provides an optical signal to RAP where the optical wavelength is converted into phase differences for feeding the antenna elements of the phased-array antenna. RG receives position information from each RAP to pin-point the wireless devices.

Localization using UWB Technique

Impulse radio based carrier-less ultra wide-band (IR-UWB) technology is considered as an ideal candidate to provide localization information for in-house environments, due to its extremely large bandwidth[2-3]. It offers a good multipath resolution and hence enables accurate localization. Furthermore, the short duration of

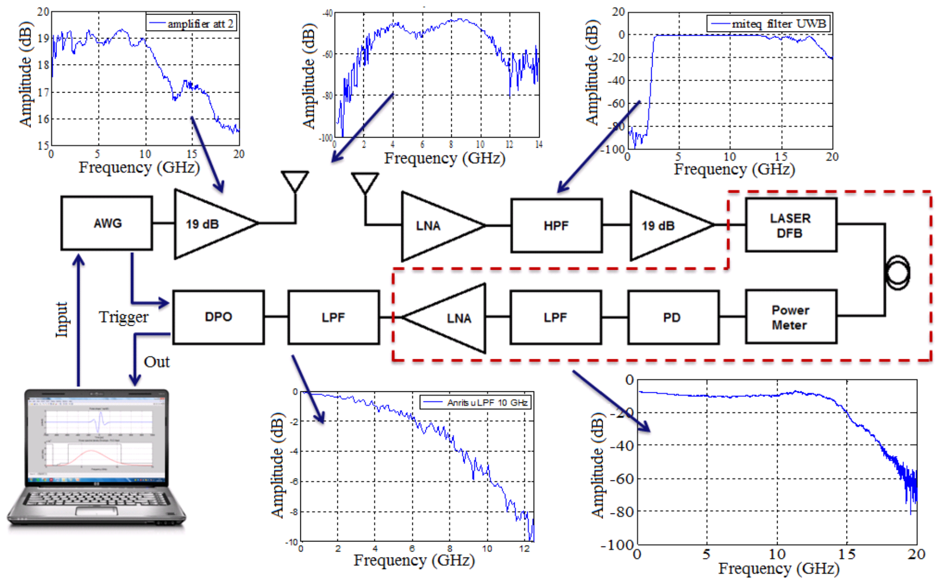


Fig. 2: Experimental setup for localization. Frequency response in various points in the setup is shown.

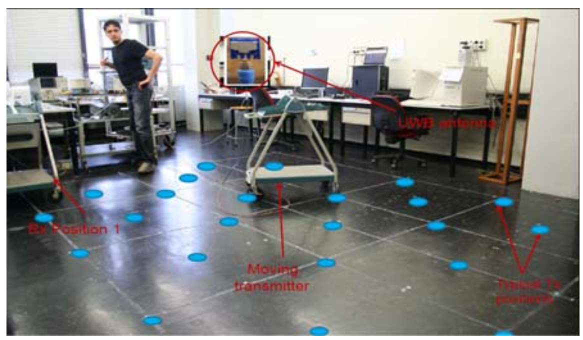
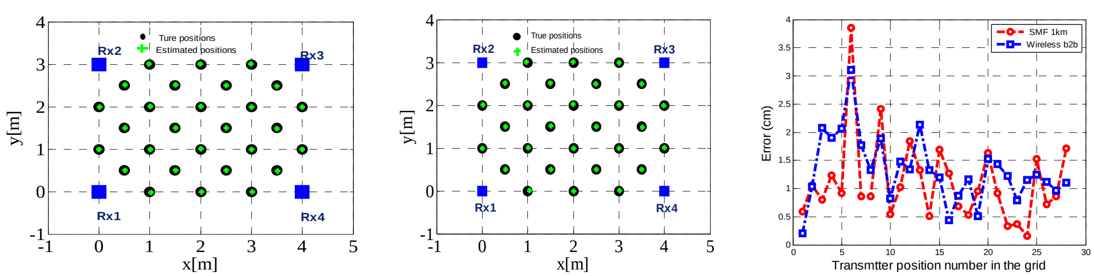


Fig. 3: Screenshot of demonstartion of IR-UWB over fiber loaclization using time-of-arrival (ToA) technique.



(a) (b) (c)

Fig. 4: Experimental results: (a) using wireless link only, (b) using 1 km SMF, (c) error of the transmitter at each position in the measurement grid.

the IR-UWB pulse (< 1ns) enables the system to provide high data rate communication[3-4].Thanks to its simultaneous capability to provide high-data rate communication and accurate localization, the IR-UWB technology employing a time-of-arrival (ToA) algorithm is an attractive solution for energy efficient and high-capacity smart in-house networks.

Experimental setup and Results

To realize ranging and localization of IR-UWB over fiber technology, an experimental setup used is depicted in Fig. 2. The localization performance was performed off-line using an arbitrary-waveform generator (AWG 7122B, 24 GSa) and a digital sampling scope (DPO 72004, 50 GSa). To meet the FCC-mask requirements, we employed our novel pulse shaping technique that is based on a linear combination of monocycles with different pulse shaping as reported in[4]. The generated pulses are amplified using a 10 GHz with 19 dB gain amplifier (SHF 100 APP) before radiation. We used commercially available UWB antennas

(Skycross SMT-3TO10M-A) at both transmitter and receiver ends. To avoid any inter symbol interference (ISI) caused by multipath signals, a low repetition frequency (PRF) of 5 MHz has been set at the transmitter side.

After wireless transmission, the received pulses are amplified using a broadband low noise amplifier (LNA) of 47 dB gain. A high pass filter (HPF) with cut-off frequency 2.6 GHz and a rejection ratio greater than 60 dB has been employed to minimize the effect of existing narrowband services. To reduce the cost of the overall optical system, we use direct modulation of a 10 GHz DFB laser at 1303.36 nm. Relevant system parameters are optimized to avoid any distortions introduced by the optical link. Accordingly, the bias of the DFB is set to 75 mA. Furthermore, the input optical power to the photodetector (PD) is limited to -3 dBm. In addition, the frequency responses of each component as well as the optical link of the system are characterized as shown in Fig. 2. Then the modulated optical signal is detected at the RG after 1km SMF-28 fiber transmission. A multimode PD with 24 GHz 3-dB bandwidth and core size of 50 µm is employed. The detected signal is eventually amplified and filtered using similar LNA and 10 GHz low pass filter (LPF). Finally, the measurement results are collected from DPO for offline processing using MATLAB.

To study the effect of fiber on the achievable accuracy, all the measurements are performed in typical office room under line-of-sight (LOS) condition with a rectangular grid of 4m by 3m as shown in Fig. 3 and Fig. 4a-b. To emulate the four corners of the room ceiling; the four receivers are placed in the corner of the grid. The transmitter moved within the rectangular grid at predefined positions as shown in Fig. 3 and Fig. 4a-b respectively. A total 28 points are considered as a position for transmitter antenna as shown in Fig. 4a-b. At each point, 200 measurements are collected and processed offline to estimate the position of the transmitter.

The collected data has been processed using two step processing approach[3]. As a first step, parameter estimation of ToA of the first direct path has been performed using energy detector (ED) based receiver architecture. This receiver architecture has been chosen due to its attractive features: low power consumption, low complexity, and hence low cost. Furthermore, it allows moderate sampling frequency compared to other type of receiver architectures[3]. In the second stage, four ToA estimates are combined and hence final position estimation has been carried out using a weighted linear least square (WLLS) estimation algorithm[3]. Based on the results observed in Fig. 4a-c, the position of the transmitter is estimated with a high accuracy for the wireless only and for wireless+1 km SMF, respectively. The maximum error found at each point in the grid shown in Fig. 4c. This high accuracy is achieved due to the combined effect of high bandwidth IR-UWB pulses; ToA based ranging technique, short wireless/fiber links and negligible chromatic dispersion of fiber at 1300 nm. The maximum location error is just 4 cm for the considered rectangular grid. However, the magnitude of this error is found to be dependent on its ambient condition. In general, the achieved accuracy indicates that IR-UWB over fiber is an attractive technology for localization of mobile stations in an in-door environment.

Conclusions

We have demonstrated in this paper an attractive localization technique that makes use of impulse-radio UWB over fiber. Utilizing the narrow pulse width of UWB signals and employing the time-of-arrival algorithm we have shown a cm-accuracy in determining the position of mobile station a rectangular grid of 4m by 3m. In addition, our observation using different types of fibers typically for optical in-house/building networks such as SMF, MMF, and perfluorinated POF showed no significant impact in accuracy. Moderate sampling rates (>2 GSa) at the receiver site did not induce a dramatic increase in the localization error (<4 cm). Our work was done using offline processing. Real-time implementation of this localization technique at relatively low-cost is feasible thanks to the performance-and-cost ratio of digital signal processing boards available now. We believe that IR-UWB over fiber technology has the potential of providing high-speed wireless data transfer and accurate localization capability for realizing an energy-efficient integrated hybrid optical/wireless communication network for home and in-building scenarios.

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