Emerging and secured mobile ad-hoc wireless network (MANET) for swarm applications

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ABSTRACT

At present, the technique of coordinating a team of robots in a manner that is responsive to communication failures, presents itself as an actual challenge. In swarm scenarios where the concept for the teams of robots requires performing cooperative tasks, robots need to be enforced to communicate with each other in the background while executing specific collaborative missions. In order to achieve complex tasks in real-time beyond their individual capability, multi-robot systems (MRS) require a stable, sustained and secure stream of data exchange. Typically, this technique also requires an approach of communication and synchronization among the robots known as swarm R2R (robot to robot) communication in real time [1]. This paper presents a theoretical concept for a wireless mesh robot network that can be protected against electromagnetic interference (EMI), electromagnetic jamming, RF denial-of-service (DoS) attacks, and eavesdropping. The team behind this paper aims to present and propose a conceptual model for a hybrid short-range modular wireless transceiver (HSMWT) used in a distributed network environment. Specific issues on designing HSMWT based on the light and sound mediums for this environment will be explored.

CCS CONCEPTS

• Networks → Network topologies • Computing Methodologies → Artificial intelligence → Robotics

KEYWORDS

Swarm, R2R, Multi-Robot Systems, Multi-Robot Network, MANET, Robot communication, mesh, network, collective robotics, Audio Communication, visible light communication, Modular wireless hybrid transceiver, Digital Signal Processing (DSP), software defined radio (SDR), flip-chip pin grid array (FPGA), On-Off Keying (OOK)

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1 Motivation and Problem Statement

Mobile robot manufacturers are incorporating more and more functions in the cloud but there are networking issues arising while using the cloud. The reliability and performance of the connected networks presents the risk of delays and loss of packets. It is very difficult to manage heterogeneous mobile robots, sensors, actuators, and other devices distributed throughout the cloud in real time. But fog computing [13] allows moving some functionalities and resources from the cloud to MRS. While cloud computing can provide powerful and scalable services for MRS applications, fog computing can provide more localized, fast-response secure mobility, and data streaming services which are more typical to the collaborative swarm robots and applications. Unfortunately, data exchange for fog based MRSs are mostly dominated by unlicensed bands of radio frequency (RF) communication with a wide variety of technologies, including protocols such as ZigBee, Bluetooth, Wi-F, among many others. MacLennan [9], concludes that the communication of swarm collaborative robot teams must either be able to maintain communications' connectivity while these are in motion, or employ recovery strategies that allow the robot team to recover when the communications connectivity is broken. IoT and industry 4.0 are also pushing requirements for fault-tolerance communication links between the nodes. But the RF infrastructure specifies possible points of failure since the unlicensed RF bands are crowded and noisy. Therefore, other types of media, such as light and sound, can be assessed.

2 Brief history

Sending and receiving information using sound or light [14] is hardly a new idea. The term "optical wireless communications" (OWC) refers to an unguided visible, infrared (IR), or ultraviolet (UV) stream of light, used to carry a signal with potential throughput – up to 10 Gbits/s. Initially, in 1993, an infrared (IR) technology was first introduced as the standard for optical mobile communication between phones and portable computers by Infrared Data Association (IrDA). Professor Harald Haas, the

Chair of Mobile Communications at the University of Edinburgh, is recognized as the founder of Light Fidelity (Li-Fi) and was the first to promote data transmission through visible light in an indoor environment [8] back in 2011. Visible light communication (VLC) uses the visible spectrum between 400 to 780 nm (400-800 THz) as shown in Figure 1. On the other hand, Ultraviolet (UV) is becoming a promising enablement technology for non-line-of-sight (NLOS) optical wireless communication, however somewhat naturally sacrificing the safety of the process.

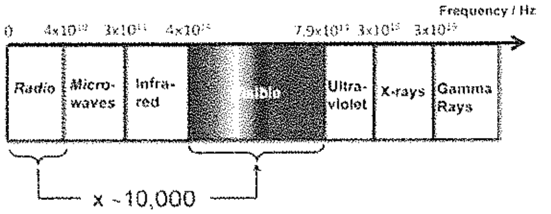

Figure 1: RF spectrum diagram

The term "ultrasonic" refers to anything above the frequencies of audible sound, and nominally includes anything over 20kHz. When being used for data communication maximum throughput is up to 100 kbit depends on the environment, frequency, modulation techniques, and distance. In 2003, P. Karimian [4] introduced a physical network layer that uses audio as the transmission medium with a broadcasting method related to the CSMA (Carrier-sense multiple access) techniques. He also describes a distributed mutual exclusion algorithm suitable for use over audio communication demonstrated it in a real environment.

3 Advantages of the proposed model

1. Security - light is effectively blocked by most barriers and has a limited propagation range, making interception from outside the testing environment and workspace very difficult, including eavesdropping and jamming attacks.
2. The progress in DSP together with open-source SDR [3] running on hardware such as FPGA boards, gives new opportunities in the effortless design signaling [5] and extended throughputs [7].
3. Easy integration - most of the mobile robots already consist of LED lights ultrasonic transducers and apparently could be utilized for communication or localization needs as well.
4. Resilient to RF interference - sound and light eliminate potential conflict with existing RF overcrowded medium.
5. Safety - visual and sound communication systems do not have harmful effects as far specific safety power limits are followed for hearing and lighting.
6. Decentralized control - HSMWT supports decentralized control and provides robustness with hierarchical control in order to achieve global synchronization and coordination [11].

4 Issues on building HSMWT for MANET

4.1 Distributed topology. Mutual exclusion.

Cooperative swarm applications promote moving some functionalities and resources from the cloud to the nodes. That is the reason the network topology in this proposition is going to follow fog computing guidelines. In this proposed networking topology we expect some of the agents would not be able to communicate to others due to a particular position and/or environment conditions, where a multi-hop function would be required. A distributed hybrid topology, characterized by no center and no fixed infrastructure, would take advantage of the resources distributed across the network and would be able to provide security and emergency applications as well. Each agent in such ad-hoc R2R network should support a routing function alongside a token-based algorithm for mutual exclusion. There are several algorithms in order to achieve mutual exclusion, so as to exclude deadlocks and starvations. The authors of this paper have selected the mutual exclusion algorithm presented by Baldoni et al. [10] "DMUTEX", used in the mobile ad-hoc wireless network (MANET). The algorithm continuously executes transitions between two states: Idle and Coordinator-Change. The main task of the Coordinator-Change state is to execute a round of a logical ring of n - 1 processes. The round starts from the coordinator Ck and does not include C k−1 Ref. [10]. As a consequence, the structure of the logical ring has to be computed on-the-fly i.e., the process Pi that receives the token has to relay it towards a process (Pi's successor) that (i) has not received the token yet in this round and that (ii) is distinct from C k−1. The last process in this logical ring relays the token to C k provoking the transition of the algorithm to the Idle state [10].

4.2 Front-end design guidelines

This transceiver is very flexible as front-end design and open to different software implementations. It can be set up in different operational modes such as MIMO, bi-directional or half-duplex. Each collaborative robot can be implemented, for instance, to a bidirectional transceiver front-end. Thus, the parallel data streams can be transmitted/received over different lights/sounds' frequencies at the same time. As compared to a single-transmitter single-receiver system using the same amount of signal power, such an array can provide higher (n-times) more data throughput with fewer transmission errors and better reliability.

Our current abstract model setup includes hybrid optical and ultrasound spectrum bidirectional transceiver with the following configuration (Figure 2 and Figure 3):

4.2.1 Low power optical module. An array of low power (LP) IR (infrared) and UVB (Ultraviolet-B) emitter/detector LEDs for bi-directional communication.

4.2.2 LED High power (HP) white emitter module. includes an array of low power (LP) IR (infrared) and UVB (Ultraviolet-B) emitter/detector LEDs for bi-directional communication.

4.2.3 R (red), G (green), B (blue) high power laser diodes (LD) transmission module. In cohabitation with optical systems (an optical lens and a diffuser) as per the experimental setup of D.

Tsonev et al., who demonstrated a 4 Gb/s VLC system at a distance of 2.88m., utilizing RGB LDs and OFDM modulation [2]. The experiment concludes that the optical wireless access data rates above 1Gb/s are possible at standard indoor illumination levels.

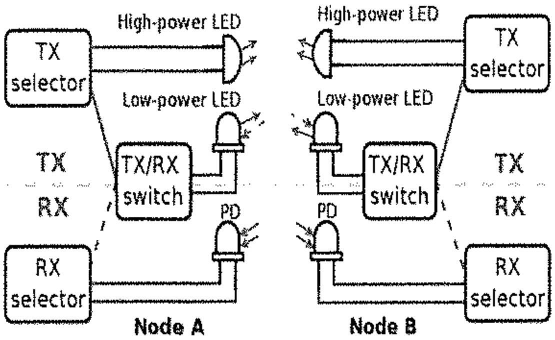

Figure 2: An example arrangement of HP/LP LEDs. Source: OpenVLC project (openvlc.org)

4.2.4 Ultrasound transducer (emitter and detector) module with 4x different frequency support - 20/40/60/80. Low bit-rate indoor communication over sound in non-line-of-sight (NLOS) room scenarios.

4.2.5 IP camera module. An additional visible light communication system by using standard IP camera (the higher fps have proven to be more efficient) detecting white robot LED but at low fervency modulation 100/120 Hz providing 300 bits/s data channel with UFSOOK modulation scheme. In one of the resource papers, researchers [12] refer to data rates up to 3 times of the camera' s frame rate. Such experiments show that non-licker cameras' communication can achieve 150 bps error-free communications for a range of up to 12 m. with 30fps @120/105Hz.

4.3 HSMWT modulation and encoding stack

Encoding "Barker binary codes" using Linear Feedback Shift Registers (LFSR) will be programmatically implemented using HDLs (Hardware Description Language) into FPGA / DSP control board as Ref. [3], [5]. "OpenVLC" is a project with a throughput of 400 kb/s at the transport layer with just one white LED and one photodiode at a distance of more than 4 meters is achieved [6]. The HSMWT would use OOK digital modulation. In OOK, the data bits 1 and 0 are represented by LED on-off respectively. In the 'off' state, the intensity of light has decreased while not being completely switched off. The main advantage of OOK is its simplicity and easy implementation. Initially, the majority of the researchers have used OOK modulation for OWC and ultrasound. Optionally "Manchester" encoding can be applied in conjunction with OOK. This method encodes a 0 into the sequence 01 and the 1 into the sequence 10 or vice versa as Manchester Run-Length Limited (RLL). This kind of chirps is known as good chirp codes called "barker codes. Interestingly, there is a Barker-2 code that is equivalent to the Manchester encoding. Galois Transform or Reed-Solomon (RS) algorithms could be applied by way of error correction with two clear advantages in the swarm scenarios explored in this paper. First of all, even at high frequencies, a long sequence of zeros followed by a long sequence of ones will be perceived as an "annoying flicker" of the LED or sound noise. Secondly, the AGC of the receiver uses the average value of the input to calculate the amplification, which is disturbed by long sequences of repeating values.

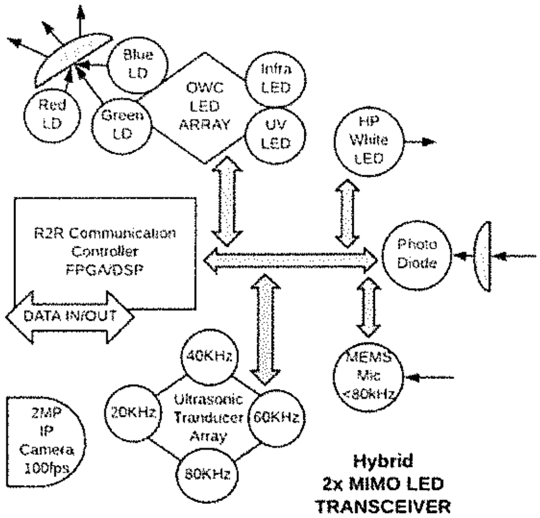

Figure 3: Flexible multi-medium (optical/sound) transceiver

5 Conclusions

At present, most of the IT industry is focused on cloud and cloud-based applications. Fog computing is yet to fully develop. This is the reason why R2R and collaborative swarm communication concepts are still out of the scope of IEEE standardization, and not able to currently meet the requirements for the emerging and secured mobile ad-hoc wireless robot network. The OWC domain is under elaborate research at present. The ultrasonic bandwidth is currently only used for communication purposes in underwater conditions and is still not a familiar technology for application in an indoor wireless infrastructure. Further research in the field of new networking architectures and topologies for fog-based scenarios are necessary, in order to involve researchers for innovative encoding and modulation approaches. More complex error correction models, protocols and routing methods should be practically tested and adopted. Comparisons with other available solutions for swarm communication would enhance further developments in HSMWT. Possible light interferences should be examined as well. Additional considerations are needed to be addressed for the safety of application.

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