On the Suitability of 6TiSCH for Wireless Seismic Data Streaming

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***Abstract*—Seismic tomography is a technique for imaging the subsurface of the Earth with seismic waves produced by earthquakes (passive) or explosions (active). A typical instrumentation deployment involves hundreds or even thousands of equally distributed data-loggers, reading from geophones, that sample typically between 250 Hz and 2000 Hz in a synchronized manner. This data is streamed outside the data-logger network for post-experiment processing. In this letter, we evaluate the suitability of IETF 6TiSCH technology for a standards-based real-time data streaming solution, and highlight the benefits of standardization in this market sector.**

***Index Terms*—Wireless seismic data acquisition, passive seismic, IETF 6TiSCH, Wireless Data transmission, Low Power.**

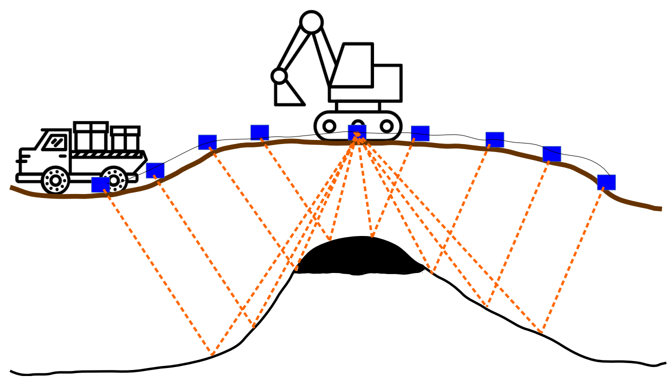

Fig. 1. A typical active seismic deployment involving dataloggers deployed on the ground and trucks that generate seismic waves.

I. Introduction

THE sub-soil exploration concept can be compared to the procedure executed by a digital camera, but instead of using a CCD optical sensor array over an area of a few square millimeters, seismic exploration uses thousands of geophone vibration sensors spread over a field of a few square kilometers. An seismic source (an earthquake, or a hammer) creates seismic waves which propagate throughout the soil and get reflected on inflection points, such as the ones created by pockets of oil. The reflected waves are recorded by surface sensors and post-analyzed to get a precise idea of the composition of the sub-soil.

Large-scale deployments typically use cabled solutions, leading to typical cable lengths of 1,000 km for medium fields and 10,000 km for larger fields. In addition, the depth of exploration depends on the total end-to-end dimension of the field, also referred to as aperture, where a larger aperture allows for greater depths. Finally, the distance between the sensors determines the resolution where a denser field yields a higher subsoil resolution.

In the last years, seismic prospection equipment has been augmented with wireless capabilities, i.e. battery operation and capacity to store the data, in order to reduce operating costs during deployments. Cabling large extensions of irregular terrain is a very labor-intensive task, which vendors and prospection companies are well-aware of. The new trend is to deploy battery-equipped devices capable of storing the collected data for post-experiment extraction. However, post-experiment data extraction is perceived as risky by the industry as the experiment costs are important, and typically cannot be repeated. Quality control (QC) mechanism are therefore progressively being adopted. The latest QC best practice exploits wireless communication technologies to extract samples of the measured data, and stream them to a central unit for pseudo real-time processing. This yields more advanced solutions that aim to stream all the data in real time.

The complexity of the wireless deployments is mainly due to the reliability expected from the network and the scale of the deployment. The devices are at ground level and propagation is subject to multi-path fading and Fresnel zone obstruction that require power amplifiers and directional antennas or complex TDMA link-layer schemes to cope with internal interference. Current approaches build complex network structures combining WiFi clusters and wireless back-hauling technologies to stream the data out of the aggregation points. WiFi Mesh technologies are being adopted to overcome the limitations of star topologies, at the cost of high energy consumption. Low-power wireless technologies are barely explored in the field due to their low data rates.

The requirements for real time data streaming in such deployments encompass the capacity to stream 250 to 2000 samples per second for different sensing channels. A sample is usually 24 bits and an experiment lasts between a few days to several months. Quality Control is another system feature where few samples of data are extracted continuously to certify the correctness of that data. This requires in the order of 20 samples per second. Nodes are spread in a regular topology and traffic is constant during the experiment. This means simple TDMA scheduling approaches can be used, with the important requirement that no sample is lost. This

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strict reliability consideration is a challenge for any wireless technology and hence one of the most important technical barriers.

This letter explores the suitability of a novel low-power wireless standard to address this application. We study the suitability of the IETF 6TiSCH protocol stack [1] – rooted in the IEEE802.15.4-2015 Time Synchronized Channel Hopping standard – to stream data from the dataloggers. We evaluate the limits of this technology and outline the most useful configurations for the target application. We also claim the benefits of standardization in this scenario, and point out some future improvements in the technology to better support reliable data streaming.

The remainder of this article is organized as follows. Section II provides a technical overview of seismic acquisition solutions, with a particular focus on wireless. Section III provides a baseline to understand the traffic requirements and network topology in the wireless seismic network. Section IV introduces 6TiSCH, and discusses the suitability of possible configurations to meet the baseline requirements. Section V presents key advantages of using the 6TiSCH technology, especially focusing on energy efficiency when compared to WiFi-based solutions. Finally, Section VI discusses the directions taken by the seismic data acquisition market, and outlines possible improvements to the standard technology.

II. Related Approaches

Enabling wireless data acquisition in seismic prospection has been a prominent development topic in the data logger industry. In this field, two different approaches have coexisted. The historical solution involves standalone battery-powered devices with local storage, but no real time data extraction capabilities. These solutions are based nodes with internal storage capabilities to store the sampled data. Recent products include wireless connectivity interfaces to extract data after the experimentation, for quality control or on-demand. In most of the cases however, devices are collected after the experimentation and racked together to a base station that extracts the data from their memories. The solutions that are developing today include wireless communicating, allowing for both real-time and off-site data transmission.

Example products include the IoN Firefly[1], a first generation wireless device using licensed band wireless communication. The product was abandoned 2011 due to the poor performance, the difficulties to cope with terrain irregularities and the high power consumption and cost.

Sercel[2], acquired Vibtech and their expertise in IEEE802.11 technologies. Their current UNITE recorder and base station uses WiFi to build a star of stars topology. It uses dual-band WiFi to link nodes to relays at 2.4 GHz. Relays then use the 5 GHz band to mesh the data to a base station. The product features high-gain antennas to allow links of up to 1 km in line-of-sight conditions. The system remains expensive and power hungry.

[1] http://www.iongeo.com/2007AR/firefly_blog.htm
[2] http://www.sercel.com

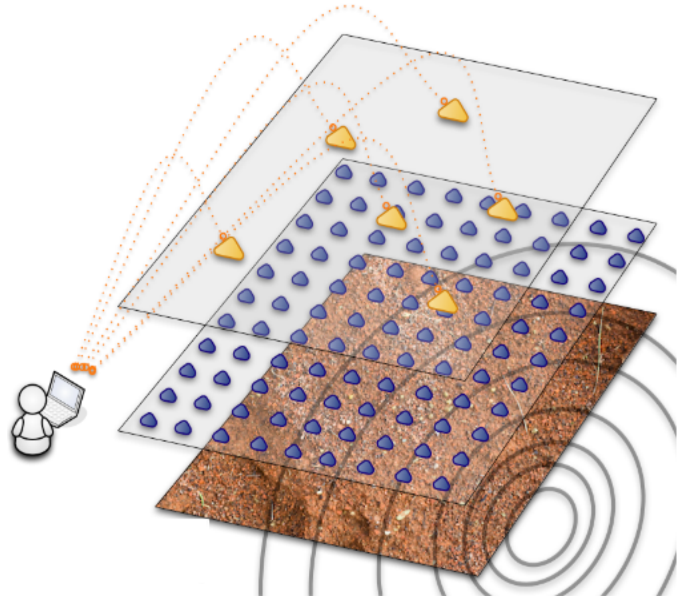

Fig. 2. Deployments are made using regular topologies where different sinks or collection devices gather date from clusters of nodes. A backhauling technology is used then to relay the data.

iSeis[3] developed their Sigma solution that provides a multi-radio communication interface. Nodes can extract status, control information and data through different wireless interfaces. Control and Status are extracted through a proprietary mesh protocol (Mesh Radio Network). WiFi Mesh and Cellular communication also offer the possibility to extract data in real time. Cellular data is of little use in remote deployments. The system remains power hungry and expensive.

Wireless Seismic[4] developed a proprietary low power mesh protocol based on low power IEEE802.15.4. They exploit a particular implementation of Time Synchronized Channel Hopping (TSCH), building a multi-hop time-slotted structure. Nodes form a mesh network with a very regular topology, usually organized in lines. Their network supports control, status and data transmission in real time. Wireless Seismic technology is ultra-low power when compared to other technologies.

III. Understanding the Streaming Requirements

In a seismic data collection scenario, the physical topology is very regular, with nodes equally-spaced throughout the deployment area. Network density depends on the type of deployment; devices can be deployed 10 m to 1000 m apart. While there is no line-of-sight across the entire deployment area, the topology is usually regular from a geographical point of view (as seen in Fig. III) redundant . Devices are usually deployed in hard-to-reach areas, and need to operate continuously for days or weeks. As a result, nodes are usually battery powered, and need to be low-power and small.

[3] http://www.iseis.com
[4] http://www.wirelessseismic.com

The total bandwidth β required for a particular deployment composed of h nodes is determined by the sampling rate n (samples per second) of the nodes in the network, the size of each sample σ (bytes), and the total size of the timestamp and metadata associated to the samples τ (bytes). β is given in (1).

$$\beta = \sum_{k=0}^{h}(n_k * \sigma_k) + \tau_k \quad (1)$$

This total bandwidth β is a key parameter when designed the network as it represents the capacity that a base station must support to collect the data.

The overhead τ can take different forms: one timestamp and metadata block for the entire set of n_k samples, or a timestamp for each sample. The former assumes sampling at a constant period; the latter lifts that requirement, at the cost of at least n_k times the size of the timestamp.

IV. 6TiSCH Capacity and Configuration

The IETF 6TiSCH working group is standardizing a set of protocols to enable IPv6 connectivity and distributed scheduling on top of the IEEE802.15.4 Time Synchronized Channel Hopping (TSCH) link layer operation. TSCH targets demanding industrial application scenarios providing higher levels of reliability[2], [3]. TSCH combines network-wide synchronization and channel hopping to achieve over 99.999% end-to-end reliability, and over a decade of battery lifetime. TSCH is the root concept for protocols such as TSMP [4], WirelessHART and ISA100.11a. In the following subsections, we describe what the capacity limits of a 6TiSCH network are, and detail the configuration trade-off to optimize the network capacity in order to address the target application.

A. 6TiSCH Capacity

The IEEE802.15.4 standard defines a data rate of 250 kbps, a maximum frame size is 127 B, and a default timeslot duration is 10 ms. This yields a maximum raw datarate of approx. 100 kbps.

Fig. 3 presents the mapping between the sampling rate n and the number of nodes h, given a fixed sample size of 24 bits and considering an IEEE802.15.4e TSCH, 6LoWPAN and UDP header overhead of 22 bytes. 6TiSCH supports different network structures for sampling rates under 1000 sps. This means the technology covers quality control data extraction and use cases for passive seismic where the required sampling rates are well below 1000 sps [5].

A 6TiSCH base station can be equipped with multiple receivers, enabling up to 16 concurrent subnetworks to be operating at the same time. In this case, the capacity depicted in Fig. 3 is multiplied by the number of available transmission channels, and leads to an interesting increment in the scale of the deployment. If we consider a deployment where nodes sample at 500 sps, with a time slot duration of 10 ms, 6TiSCH can handle 8 devices for each communication channel. When using the 16 available channels[5], a single base station can support up to 128 devices transmitting simultaneously.

[5] between 2.405 MHz and 2.480 MHz.

TABLE I
Frame Control Field configuration for smallest packet size

	Type	Security Enabled	Frame Pending	ACK Requested	Intra-PAN	seqnum Suppression	IE Present	Destination Addr. Mode	Frame Version	Src. Addr. Mode
Data	01	1	0	1	0	1	0	10	10	10
ACK	10	1	0	0	0	1	1	10	10	10

B. 6TiSCH Configuration

In order to optimize the 6TiSCH protocol stack, the IEEE802.15.4 TSCH MAC layer needs to be configured to minimize the header length. According to the minimal 6TiSCH profile [6], once the network has formed, nodes use short addresses and PANID compression. The Frame Control (FCF) field of the IEEE802.15.4 header should be used with the configuration depicted in Tab. I, leading to a MAC layer header size of **12 bytes**, including the security header and FCS. The 6LowPAN [7] header accounts for an addition 4 bytes, because of the 6LoRH header [8], assuming one page and carrying the RPL RPI option for routing purposes [9]. The IPHC header [10] adds another 2 bytes, using the UDP compressed Next Header (NH) and full IPv6 address compression. UDP adds an overhead of 2 bytes, assuming the CRC is elided and a UDP port in the range 61617-61624 is used [10]. This leads a total overhead of 22 bytes for all headers, leaving 105 bytes for application data.

To further optimize the bandwidth, the signaling overhead of the protocols needs to be minimized. This is achieved by the 6TiSCH distributed operation layer. 6TiSCH has developed a configuration profile [6] that enables a network to form a simple control and data plane for nodes to join. Once the network has been formed, distributed scheduling policies – referred as “Scheduling Functions” – operate in a distributed manner, and reserve the required resources to meet the application communication requirements [11], [12], [13]. The routing topology is maintained by the RPI header once the network has been formed. RPL DIO and DAO message periods can be significantly reduced as 6LoRH routing extension headers update the topological information. Once a data collection experiment starts, the stable bandwidth requirement reduce the control plane overhead as the schedule of the network is already configured. In addition, network synchronization is maintained with no additional overhead.

V. Energy Consumption Evaluation

We model the network schedule of a device, taking into account the maximum supported throughput, and evaluate its energy consumption based on a well-establish energy model for TSCH [14]. This model computes the energy spent by a node as a function of the type of slot (sleep, transmitting, receiving, idle listening).

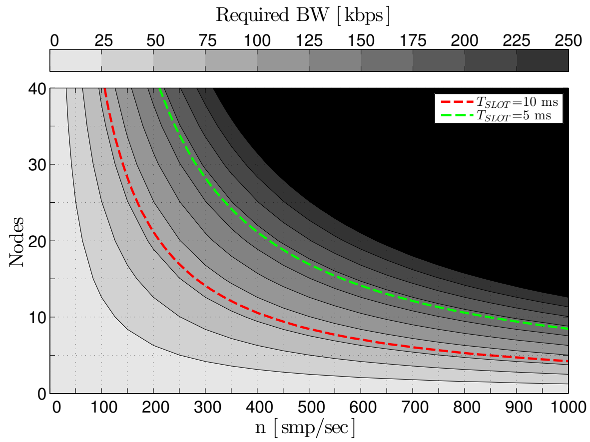

Fig. 3. Network capacity in relation to the number of nodes in the network considering header overhead. Red and green lines delimit the capacity for 10ms and 5ms slot sizes.

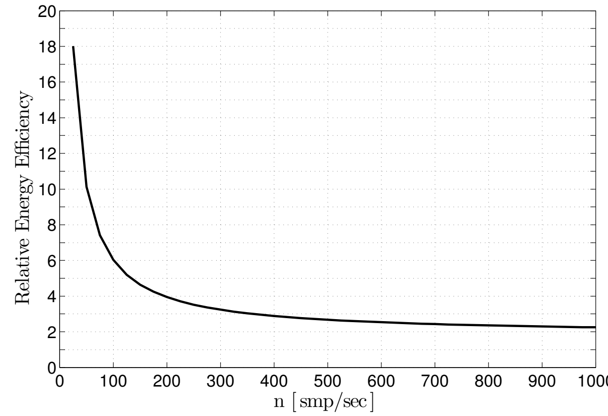

Fig. 4. Relative energy efficiency of a 6TiSCH node when compared to WiFi in relation to the sampling rate.

TABLE II
SUMMARY OF THE IEEE802.15.4 AND IEEE802.11 CHIPSETS

	TX Current (0dBm)	RX Current	Data Rate
TI CC2650	6.1 mA	5.9 mA	250 kbps
TI CC3200	250.0 mA	53.0 mA	6 Mbps

We compare those results to WiFi, with the same traffic requirements. The WiFi model considers that the energy consumed by an 802.11 device is dominated by the type of operation: (i) the idle consumption, (ii) the energy spent by the protocol stack when transmitting the packet, (iii) the power required to transmit the packet, (vi) the power consumed in retransmissions, (v) the reception power, (vi) the energy overhead of processing the received frames , and (vii) the energy spent on sending and receiving ACK frames.

We assume we are using an IEEE802.15.4 TI CC2650 in the TSCH case, and an IEEE802.11 CC3200 in the WiFi case. Both chips are representative to the technology at the time of writing. Datasheet numbers for both chips are summarized in Table II.

Fig. 4 presents the energy consumption of a WiFi and 6TiSCH based solution. We model the best-case connectivity in which there are not WiFi retransmissions. The advantage of using 6TiSCH over WiFi at low sampling rates is clear.

VI. CONCLUSION

This letter discusses the suitability of the IETF 6TiSCH protocol stack for real-time wireless seismic data acquisition. It presents the 6TiSCH protocol configuration to maximize network capacity. 6TiSCH can support clusters of up to 128 nodes per gateway, enabling a reliable real-time network for sampling rates below 1000 samples per second. Moreover, due to the low-power characteristics of IEEE802.15.4, the energy consumption is several times lower than WiFi.

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