Wireless Technology for Process Measurement on Oil and Gas Facilities

Merle Fernandes

David Huang
School of Electrical and Electronic Engineering

Celeste Savanyo
CEED Client: Woodside Energy Limited

Abstract

Wireless instrumentation is rapidly gaining recognition in the oil and gas industry as a catalyst for optimised modularisation – a construction tactic in which the units of an LNG process train are built overseas and shipped in their entirety to site, massively reducing costs. Wireless instruments compliment this approach by removing the need to lay communication cables during the construction phase. Wireless instruments exchange information according to wireless communication protocols. These models conceptually break complex networks into simple layers and define the strict rules which coordinate message packaging, routing and transmission. WirelessHART and ISA100.11a are the two main wireless communication protocols in industrial sectors, however their incompatibility alongside a split market, creates disorder for operators such as Woodside. This paper provides the engineering arguments to determine which protocol is better suited to Woodside assets, by simulating wireless sensor networks configured in either protocol. Throughput, reliability and battery life were the key performance indicators, to compare the WirelessHART's Time Division Multiple Access channel versus ISA100.11a's Carrier Sense Multiple Access approach. Higher throughput statistics were achieved for ISA100.11a, whilst WirelessHART was more efficient in power consumption. This project also looks at the requirements and limitations of wireless technology in terms of monitoring versus safety and process control.

1. Introduction

Woodside Energy Limited is an Australian, independent oil and gas company whose primary role involves the extraction and processing of natural gas and petroleum from sub-sea wells. Instrumentation devices play a key role in the monitoring, control and safety of facilities. Whilst typically wired, Woodside's "Development Technology" divisions are exploring the trend towards wireless instrumentation technology. Optimised modularisation is known to reduce capital expenditure and wireless technology perfectly suits this option because it allows for the construction of modules to be performed elsewhere, independent of cabling.

Wireless sensor networks (WSNs) follow unique rules in cyberspace which dictate every interchange from information measurement, packaging and transmission to reception and decoding for the user. These rules are called communication protocols and unique versions exist for varying applications.

1.1 Background Information

Communication protocols are defined using what is known as an Open Systems Interconnection (OSI) stack, which helps break a complex network into smaller manageable layers. The stack is hierarchal in the sense that each layer requests and receives information from the layer below it whilst hiding those details from the layer above. In turn, a layer provides information and services to its overhead neighbour.

The drive to produce a communication protocol adequate for industrial monitoring resulted in the introduction of the WirelessHART (IEC 62591) in September 2007 (Peterson, Carlsen 2012) and sometime later the ISA100.11a (IEC 62601) in September 2009 (Peterson, Carlsen 2012). Both are derived from the IEEE standard 802.15.4 for Low-Rate Wireless Personal Area Networks and while essentially encapsulate the same practice, are configured with several fundamental differences. The differences between the two protocols can be seen in Figure 1.

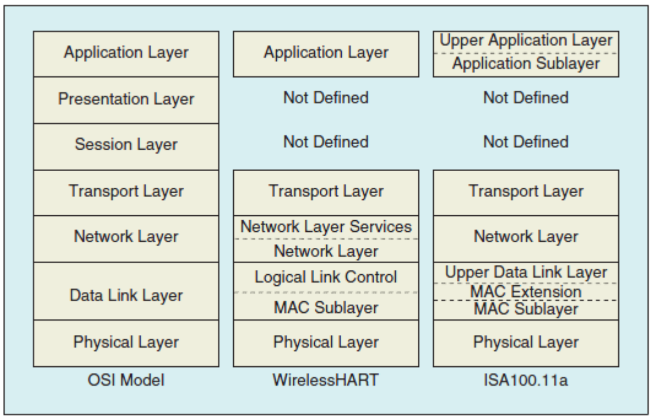

Figure 1 The WirelessHART and ISA100.11a Stack models (Peterson, Carlson 2011)

The most crucial difference, reinforcing the inability of the protocols to merge, lies in the MAC sub-layer for Medium Access Control. Slot time is defined as the "awake" period of a device, when it is actively sending or receiving. WirelessHART maintains a 10ms slot time in a TDMA (Time Division Multiple Access) control. In ISA100.11a protocol however the channel is left open for a CSMA (Carrier Sense Multiple Access) control. Further differences exist, related to network topology and network addressing.

1.2 Project Objectives

The market of instrumentation devices is predominantly divided between the two wireless communication protocols. This division in products may cause uncertainty for instrumentation engineers at Woodside. Thus the drive for this project is to simulate networks configured in either protocol and highlight key performance indicators to distinguish which protocol has better characteristics. The analysis of results may provide clarification for future front end engineering design.

2. Methodology

The simulations were performed using NS-3 Network Simulator. NS-3 is a discrete event network simulator for Internet systems targeted for research and education. NS-3 is free online, licensed under the GNU GPLv2 license and is publicly available for research, development and use. Collaboration with the instrumentation and control team from Nganhurra facilities engineering provided the base network topology from which the simulation was developed.

2.1 Framework of the Simulated Network.

To maintain compatibility with Woodside assets, the frame of the network was modelled after an existing wireless sensor network. A WSN was created aboard the Nganhurra Floating, Production, Storage and Offloading (FPSO) vessel, as a trial for the monitoring and record of leak tests on the riser emergency shut-down valves. The network has been running successfully utilising a WirelessHART communication protocol for over two years (Barini E, pers. comm., June 5, 2013). By configuring the simulations as close as possible to the actual network, minimal assumptions were made in regards to environmental variables. The figure below shows the Nganhurra FPSO and approximate placements of four wireless pressure transmitters, three wireless temperature transmitters and one access point.

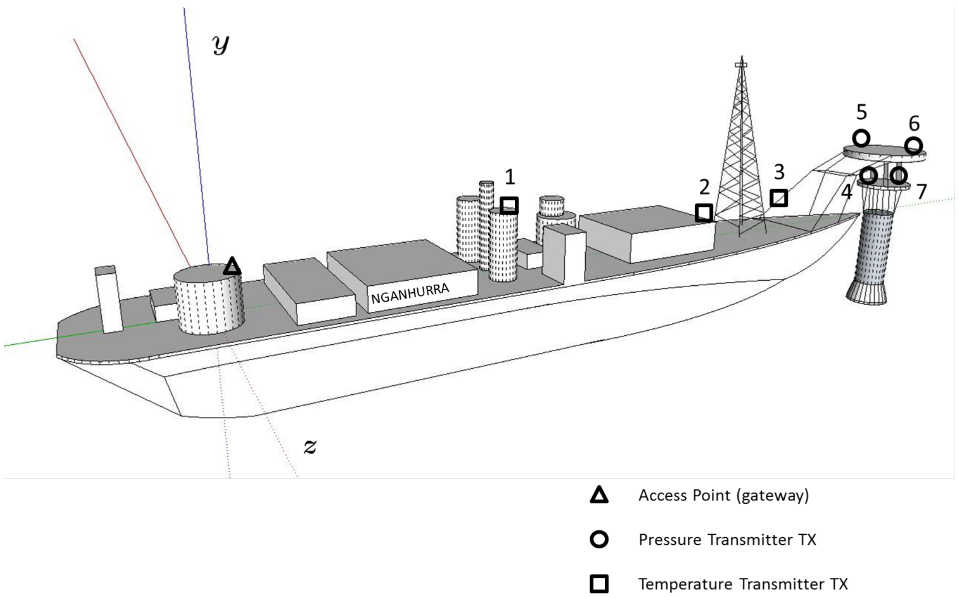

Figure 2 Woodside's Nganhurra FPSO with the approximate locations of gateway, temperature and pressure transmitters. Numbers indicate device number as aligned with the simulation. The entire vessel is approximately 260m in length and 50m in width. Schematics provided by the Nganhurra instrumentation and control team.

The algorithm followed by NS-3 programmers creates a node, within which a programming interface can configure layers of the OSI model. Each node represents a computer or transmitter on the network. Within the node, net devices hold information about lower layers such as the physical specification of channel transmission and medium access control. An interface container ties the lower levels with the upper functions responsible for the information's source and destination.

The physical layer utilises a hybrid of Direct Sequence Spread Spectrum (DSSS) and Frequency Hopping Spread Spectrum (FHSS) for maximum robustness against process interference. The simulation used an IEEE 802.11b Wireless Local Area Network (WLAN). Industrial networks are typically modelled as per the IEEE standard 802.15.4 for Low-Rate Wireless Personal Area Networks (LR-WPAN); however this module is still under development in NS3. Channel properties were determined as per previous literature (Nobre et al. 2010). These parameters can be seen in Section 3. The transmitting devices were defined as sources and the gateway as a sink. A User Datagram Protocol (UDP) data flow was implemented for the generation of normal traffic, at the transport layer. The 802.11b standard allows transmission on the Industrial, Scientific and Medical bandwidth 2.4GHz at data rates spanning 1Mbps to 11Mbps (Zhao G 2011). Optimised state link routing (OLSR) was implemented using in-built functions of the software.

2.2 Differentiating the WirelessHART and ISA100.11a

The most fundamental difference between the ISA100.11a and WirelessHART constituted the MAC (Medium Access Control) sub-layer. This layer defines the process by which a device checks and clears the channel for the transmission to commence. WirelessHART follows a Time Division Multiple Access (TDMA) protocol for coordinating multi-device communication on a single network. The basic principle is that transmission is divided up into super-frames, within which, each device is allocated a slot. The MAC operates on a round robin system. Each device may only transmit in its allocated section and is otherwise 'idle' to conserve power. WirelessHART uses a fixed slot time of 10ms. The ISA100.11a also uses a TDMA data link with a significant variation. Slots may remain on the same frequency channel for an extended period. This slow hop may be shared by a number of devices, leaving data linkage in that time to be dominated by a Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). This method involves the device "sensing" whether the channel is free by submitting RTS/CTS (Request To Send/ Clear To Send) prompts. (Peterson, Carlsen 2011).

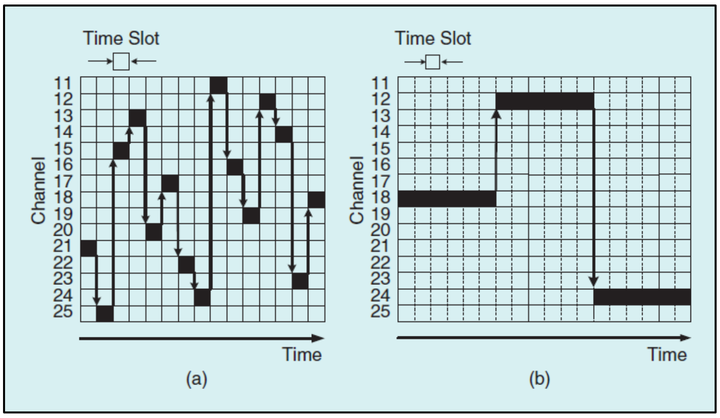

Figure 3 Time slots showing (a) Slotted Frequency Hopping and (b) Slow Frequency Hopping. Within each extended slot in (b), CSMA/CA dominates. (Peterson, Carlson 2011)

The WirelessHART protocol assumes all devices have routing capability, hence allowing a mesh topology with all devices free to route on an optimised link convention. The ISA100.11a separates the sensor role from the router, hence the availability of "end nodes" with no routing capability. This permits a star-mesh topology. In the simulations, nodes 5, 6 and 7 were defined as end nodes only capable of forwarding information to node 4 (See Figure 2).

2.3 Key Performance Indicators

To date the performance indicators used to benchmark the simulation results are a measure of throughput, packet loss and battery consumption. A flow monitor uses probes which can tap into devices and read its diagnostics. Network throughput is the average rate of successful transmissions and is measured in bits per second. A counter keeps track of dropped packets. These two features provide the benchmark for network reliability.

Field instruments aim to conserve as much power as possible as this minimises the need for maintenance. As such, much emphasis is placed on the ratio of idle mode to active mode. To observe this behaviour an energy source container was implemented which modelled the depletion of lithium thionyl chloride batteries. Power consumption was modelled after a typical wireless CC2420 radio chip, such that sufficient power depletion could be observed in 100 seconds. The actual life expectancy of wireless instruments may be up to 10 years, depending on the refresh rate of information.

3. Analysis of Simulation Output

The simulation yielded the following outputs for the given parameters:

Packet Size (payload) = 60 Bytes	RTS retry limit = 2 attempts
Number of Packets = 10 000	TDMA slot time = 10ms
Data Rate = 11 Mbps	Initial Cell Supply Voltage = 24V DC
Propagation Delay Model : Constant Speed Propagation Delay	Battery: Lithium Thionyl Chloride Cell Model Battery ‘TX’ current : 17.4mA
Propagation Loss Model: Log Distance Propagation Loss	Battery ‘RX’ current : 18.8mA Battery ‘idle’ current : 426uA
Maximum Transmission Range = 150m	Battery ‘sleep’ current : 20uA

Table 1 Simulation Parameters.

	Total Throughput	TX drops	RX drops	Battery Usage
Access Point	-	-	0	0.0242V
Device 1	14.3298 Kbps	0	0	0.0189V
Device 2	14.3285 Kbps	0	0	0.0129V
Device 3	14.3286 Kbps	0	0	0.0124V
Device 4	14.3272 Kbps	0	0	0.005V
Device 5	14.3274 Kbps	0	0	0.0052V
Device 6	14.3276 Kbps	0	0	0.005V
Device 7	14.3277 Kbps	0	0	0.0032V

Table 2 Results of the WirelessHART simulation package. Throughput was a measure from each device source to the access point.

	Total Throughput	TX drops	RX drops	CTS timeout drops	ACK timeout drops	Battery Usage
Access Point	-	-	0	-	-	0.0242V
Device 1	14.3305 Kbps	0	0	0	0	0.0234V
Device 2	14.3305 Kbps	0	0	0	0	0.02V
Device 3	14.3306 Kbps	0	0	0	0	0.02V
Device 4	14.3306 Kbps	0	0	0	0	0.0136V
Device 5	14.3307 Kbps	0	0	0	0	0.0032
Device 6	14.3307 Kbps	0	0	0	0	0.0032
Device 7	14.3307 Kbps	0	0	0	0	0.0032

Table 3 Results of the ISA100.11a simulation package. Throughput was a measure from each device source to the access point.

It was hypothesised that the ISA100.11a packet drop would be greater than WirelessHART. This is because the ISA100.11a cannot guarantee a clear channel and must confirm the channel's availability. Consistent with the Nganhurra network, 100 seconds of simulation time, is insufficient to guarantee a packet drop as both networks are robust and relatively uncongested. Future work will be to manipulate the network parameters to focus exclusively on these bench-markers. This requires pushing traffic and interference to improbable limits and observing network reaction. Scheduled work requires testing additional properties of the network, in particular, response to network "jamming" and response to node failure.

ISA100.11a, with its more complex features proves more successful in terms of throughput. An interesting observation shows the devices closer to the access point are more reliable in a WirelessHART configuration, whilst the reverse is true for the ISA100.11a. This provides some insight as to where higher network congestion occurs. In larger networks, ISA100.11a is prone to experience more congestion at the star-mesh interfaces.

As predicted, WirelessHART conserves more power in centrally placed routers because the devices are able to restore and even regain power during sleep mode. Because this simulation configures all devices on the same channel, the ISA100.11a devices must always be at best idle which comes at the expense of power use. The three nodes on the star network however, conserve the most power due to their non-routing status.

4. The Future of Wireless Technology

Further to the simulations, a feasibility study will investigate the applications of wireless technology. Currently wireless is accepted only in monitoring scenarios, considered too unreliable for critical control and safety. Future projects should test the BER (Bit Error Rate) during simulations, as control and safety applications require operation within 99.9% reliability (Peterson, Carlsen 2012).

The implementation of devices such as wireless gas detectors and WirelessTHUMs will also be explored. Wireless gas detectors complying with the adequate Safety Integrity Level may soon be approved as safety applications. WirelessTHUMs are diagnostic devices which offer the ability to monitor processes previously unseen, extending to rotating equipment and confined space areas, enhancing productivity. This project will aim to explore these solutions and their potential as Woodside assets.

5. References

Nobre, M. Silver, I. & Guedes, L.A. (2010) Towards a WirelessHART module for the Ns-3 Simulator, *IEEE Emerging Technologies and Factory Automation* pp. 1- 4.

Peterson, S. & Carlsen, S. (2011) WirelessHART Versus ISA100.11a – The Format War Hits the Factory Floor, *IEEE Industrial Electronics Magazine* pp. 23- 34.

Peterson, S. & Carlsen, S. (2012) Wireless Instrumentation in the Oil & Gas Industry – From Monitoring to Control and Safety Applications, *Society of Petroleum Engineers*.

Zhao, G. (2011) Wireless Sensor Networks for Industrial Process Monitoring and Control: A Survey, *Macrothink Institute: Network Protocols and Algorithms* (Vol.3) pp. 46- 63.