Wireless Protocols for Critical IoT

Case study.

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NIST measurement campaign

A public study was conducted by the NIST (National Institute of Standards and Technology, USA) to finely measure the communication channel in different industrial environments in order to check, by analysis, that the use of current standards offers a solution adapted to these environments. A summary of the measures and studies is available in full here :

`http://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.1951.pdf`

Measurement locations An extract of the final report based on these measurements has been distributed to you. In this report, we present the industrial environments where the measurements were taken. It also offers a description of the measurement conditions.

Q1. Understand Describe the measurements that were carried out and the 3 industrial environments from the documents provided to you.

Q2. Delay spread et 802.15.4 One of the conclusions of the report is the presence of a strong channel spread due to the presence of obstacles in industrial environments. The IEEE802.15.4 technology has a bit rate of 250 kbits / s, and a symbol rate of 62.5 ksymbols / s. Does such a multi-path communication channel greatly degrade the transmission of IEEE802.15.4 frames ? Please, justify your answer.

Solution :
Measurements show that there is a channel spead up to 300ns (cf. Figure 4.3.1-(a) automotive environment). To demodulate the signal, the duration for transmitting a symbol should be way larger than the worst channel spread.
Duration of one symbol @62.5ksymbols/s : 16 microseconds.
This duration is roughly 50 times larger than the max channel spread of 0.3 microseconds. Thus, the slow emission rate of IEEE802.15.4 is robust to industrial channel spread.

WirelessHART

The WirelessHART protocol is based on the digital communication chain of IEEE802.15.4. In this technology, a centralized controller defines a superframe where each slot lasts 10ms. An acknowledged communication (transmission of the frame + ACK) can be carried out in a slot. The maximum size of a transmitted frame is 127 bytes.

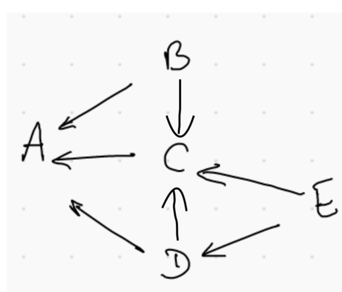
Q3. First verification Is it possible to send a frame of maximum size and an ACK in one 10ms slot ?
Solution :
The duration for sending 127 bytes at 250kbits/s is : $127 * 8/250000 = 0.004064 \sim 4$ milliseconds.
The ACK frame size is much smaller than a regular DATA message, so sending DATA + ACK fits into a 10ms slot duration.

Frequency hopping Similarly to the TSCH mode of IEEE802.15.4, WirelessHART leverages frequency hopping. There are 16 orthogonal logical channels that can be assigned to a communication link. For each logical channel, at every superframe, the actual frequency between the source and destination nodes changes.

In Wireless HART, and this is different from TSCH, the ressource allocation is made by a central controller that decides on the assignment of time slots and logical channels to a communicating pair of nodes (source to destination node).

Q4. If we assume that a superframe is composed of 10 time slots, please plot one of the possible allocations that can be made by a controller that wants to assign 7 links created by the transmissions of 5 nodes as follows :
— B transmits a data frame to A and C
— C transmist a data frame to A
— D transmits a data frame to A and C
— E transmits a data frame to C and D

Solution :
Emissions are the following ones :



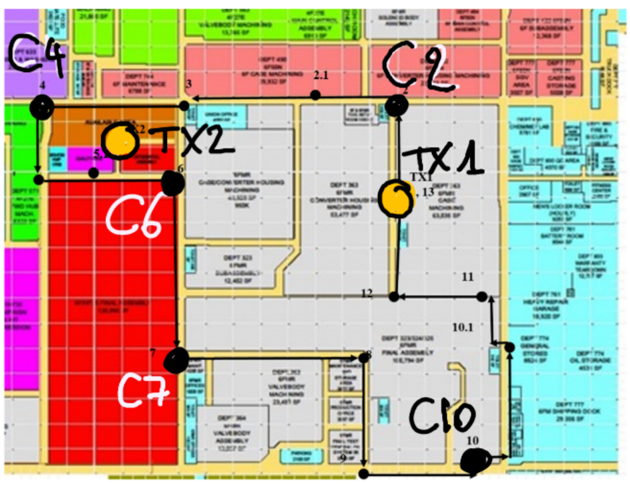
We have 10 time slots in total, and 7 links to allocate. Node A and C can't receive or send multiple frames in the same time slot. One possible allocation :

Time slot

freq. Offset	1	2	3	4	5 …
0	B→A	E→D		E→C	
1	D→C	C→A			
2			D→A		
3			B→C		

Rolling out WirelessHART We are interested in the deployment of sensors on the *outer loop route* of the automobile assembly plant. We want to deploy the following wireless sensors :

— At point 2 : Sensor C2 emits a frame every 60ms.
— At point 4 : Sensor C4 emits a frame every 90ms.
— At point 6 : Sensor C6 emits a frame every 180ms.
— At point 7 : Sensor C7 emits a frame every 60ms.
— At point 10 : Sensor C10 emits a frame every 40ms.



Q5. Assigning sensors to Controllers Two controllers (APs) are rolled out at the locations of TX1 et TX2 antennas. They only collect the data transmitted by the sensors. We will call these two controllers TX1 et TX2 as well.

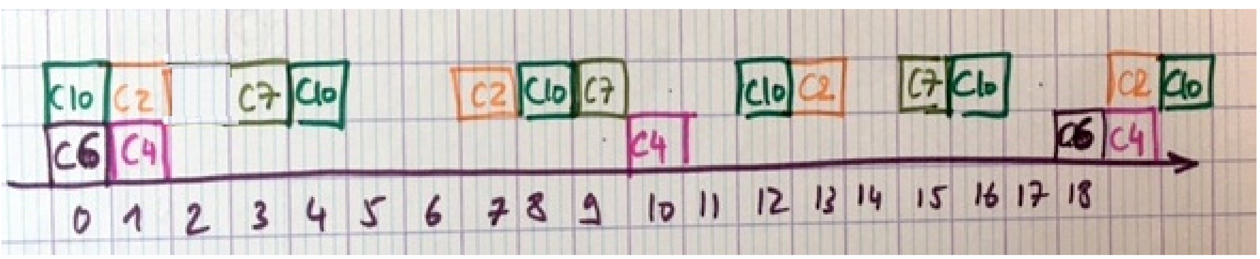
Which access point could we associate the 5 sensors with ? What are the elements that would help us in making this association ?

Solution :
Communication nodes are generally assigned to the APs offering the best coverage : best received signal strength, best data rate, etc. In free space, since path loss is inversely proportional to the distance between node and AP, the best option is to pick the closest AP. In industrial environment, this is not the case. If we have access to the measurements made, we should decide based on the best signal received at each node : for instance, if C7 receives more power form TX2, you should assign C7 to TX2. We don't have this specific informations here, but distance still plays a role. We can easily decide this based on distance :

— TX1 associated to C2, C10
— TX2 associated to C6, C4
The point which is not clear, is whether to assign C7 to TX1 or TX2. Let's take the arbitrary decision to assign it to TX1.

Q6. Size of the superframe Propose the size of the superframe allowing all these flows to be transported by assuming that the sensors are associated with the controllers as follows :
— C2 associated to TX1.
— C4 associated to TX2.
— C6 associated to TX2.
— C7 associated to TX1.
— C10 associated to TX1.

Solution :
In this question, we have to account for the periodicity of the flows and the way flows are transmitted :
— Flows of C2, C7 and C10 can't be emitted in the same time slot.
— Flows of C4 and C6 neither.
The least common multiple of the periods of the flows is LCM(40, 60, 90, 180) is 360ms, but if we reduce the set to the flows handled by TX1, we can create a superframe of LCM (40, 60) = 120ms. Same for TX2 with a LCM (90, 180) of 180ms. Important is that the flows of TX1 and TX2 are sent on a different frequency offset. So both APs can announce a different superframe, but the global superframe, of duration 360ms, is like that :



Q7. ARQ To make communication more robust, each transmission is allocated two communication slots, in two consecutive superframes. How to reserve these redundant slots in the superframe ?
Solution :
How many frames will be sent to TX1 ? TX2 ?

— TX1 : In 120ms, C2 and C7 emit 2 frames (1 every 6 slots), C10 emits 3 frames (1 every 4 slots).
— TX2 : In 180ms, C4 emits 2 frames (1 every 9 slots) and C6 emits 1 frame.
For TX2, we are sending 3 frames every 18 slots. If we give 2 slots per flow, we need 6 slots out of 18. It is easy to construct a schedule like that.
But for TX1, we need 7 * 2 frames out of 12 : we need another frequency channel to accommodate all these flows.
A possible superframe could be one where we assign to :
— Channel 0 : C4 and C6.
— Channel 1 : C10 (2 frames every 4 slots)
— Channel 2 : C2 and C7.

Q8. Mesh network We realise that the error rate on the link which connects C7 to TX1 is too high. We then configure C6 so that it becomes a router and retransmits the frames from C7 to TX2. How to modify the superframe to integrate this routing operation ?

Solution :

We need C7 to send frames to C6 - we can keep the transmission of C7 in channel 1, as long as the slot of C7 doesn't overlap with the slot when C6 transmits to TX2 (this is the case in the previous figure)

We need as well to create a second slot for C6 to send the date of C7 to TX2, making sure that this second slot of C6 is not at the same time than the slot of C7.