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Short Range Wireless Network : a Real Time Case Study

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Abstract – Wireless communication is the fastest growing segment of communication today. Short range wireless devices conformant with 802.15.4 or blue tooth technologies are slowly advancing to replace wired devices but still many technical challenges like robustness, reliability and speed in general need be addressed to face the challenges of the future. This paper evaluates the prohibitive issues of short range wireless technology for their rapid and efficient deployment in the real time applications. A case study of switch over from wired to wireless environment for a real time implementation for Indian Railways is presented. The work presents threshold LQI based connectivity confidence matrix which reduces the problems of formation of asymmetric link and shows improvement in reliability of the communication. The case study also highlights the necessity of application independent communication model paving a way to cost saving.

Keywords – short range wireless network, threshold LQI, asymmetric link , application independent network layer

1. Introduction

The WiFi and WiMax are spearheading the technologies for inter networking in data communication world. The cellular technology has virtually replaced land line phone networks laid across the world. Another type of wireless network, Short range wireless networks are slowly advancing to replace wired devices. These technologies; Bluetooth, 802.15.4 LR-WPANs for small size networks are making their significant impact in real world. However they are far from competing with wired communication in terms of robustness, reliability and speed in general[1].

The benefits of the wireless network are superseding the wired networks. Ease of use, less time to market, easy to install at difficult places are some of the benefits of wireless technology. These features are very appealing for small networks in physically bounded areas like smart homes, industrial network, special purpose embedded device network etc. Availability of plethora of short range wireless trans-receivers has made it mandatory for the industry not to overlook wireless alternative for such networks.

The foremost problem for not deep penetration of wireless technology in industrial and commercial application areas is lack of standard network suits or protocols which will allow end user to smoothly transit on to wireless communication. The working groups such as wireless industrial networking alliance (WINA), Wireless HART from HART communication foundation (HCF), and ISA100 have tried to define and establish industrial wireless-technology standards for different application domains [2]. More specific groups working on similar short distance wireless communication standards are Bluetooth, UWB, ZigBee, IEEE 802.15.4a, WiBree, and Rubee. They bring multiple choices for various short range wireless applications[3]. These groups are working towards evolving protocol standards satisfying industrial needs and challenges. The standards are based on focused application areas thus not satisfying application independent network protocol requirement.

There are some real time implementations carried out using different technologies showing strengths and weaknesses of the short range wireless communication. The Bluetooth has been implemented for wireless sensor network for security systems[4]. Use of Zigbee technology has been demonstrated for industrial control specifically for loom control[5], Automatic Meter reading systems[6] and intra-car wireless communication network [7] . There is a transport system implementation using WSN[8]. A survey of application distribution in wireless sensor network[9], has presented various wireless sensor network technologies in turn short range wireless networks. Author has observed that Operating systems (OSs) and middleware architectures for WSN implements separate services for distribution within existing constraints but an approach providing a complete distributed environment for applications is absent.

The present work examines challenges, real time characteristics and advantages of wireless networks. A real time case study of Indian Railways is presented with proposed solutions to alleviate implementation challenges. Section 2 discusses the wireless media behavioral characteristics, their impact on communication protocols, other problems faced by application developer to use wireless communication media and necessity of application independent network protocols. Section 3 presents case for consideration of using wireless media for communication. Section 4 provides proposed solutions with implementation details of system under transformation. Section 5 presents experimentation and results to validate proposed solutions and requirement specifications of the system. Section 6 gives conclusion inspecting the solutions, results and their reusability in the different application scenarios.

2. Challenges for Short Range Wireless Communication

Short range wireless technologies suffer heavily in their performance metrics due to wireless-link quality dynamics, noise, interference and environmental impact on communication range and reliability as compared to WiFi and Wimax wireless technologies. Following section discusses major impacting factors and other aspects prohibiting the growth of short range wireless networks.

2.1. Irregularity of Radio Communication

In models and solutions for radio irregularity[10] has noted three properties of radios which has maximum impact on short range wireless communication; Anisotropy, continuous variation and heterogeneity. The radio signal from a transmitter has different path losses in different directions and the wireless coverage is not spherical as is widely assumed. Secondly the signal path loss varies continuously with incremental changes of the propagation direction from a transmitter and the differences in hardware properties and battery status lead to different signal sending powers, hence different received signal strengths. Further with an experimental study in understanding packet delivery performance in dense WSN has shown that asymmetric link percentage can be as high as 40% in short range radios greatly affecting the network performance[11]. This issue becomes crucial for short range radio network as the percentage of irregularity is severely high as compared to its coverage capability. Empirical measurements has demonstrated that the average LQI values provided by WSN radio components are closely correlated with PRR and can be used as a reliable metric for wireless-link-quality assessment during the deployment of the proposed WSN scheme[1]. LQI as function for packet yield has been used and have observed that LQI is a quite good indicator of packet yield, as there is a strong correlation between LQI and packet yield for similar experiments[12]. Author has also noted that packet yield as a function of distance depends very heavily on height of both the sending and receiving motes. In most situations sensor nodes will have to be deployed on walls and floors, where they will not be able to achieve their full range. Use in the intra-car sensor network has reported two issues due to low LQI values, fading ("long-term" problem): passengers causing channel fading and Interference ("short-term" problem): frequency hopping interference[7].

2.2. Software and Hardware Issues for Transitioning to Wireless Communication

Another issue is software and hardware for switching to the wireless network for existing wired networks and new applications. Merill in "Where is the return on investment in Wireless Sensor Networks?" , has observed that there is too much diversity of hardware and application building platforms[13]. The author has also noted that application specific software development cost exceeds hardware design and manufacturing cost due to excess availability of various wireless and embedded hardware devices and unavailability of standard framework to work in this heterogeneous scenario.

2.3. Economics of wireless networks

The cost difference between wireless media devices than their wired counterpart is aggressively decreasing due to availability of many radio trans-receivers in various shapes, types, forms and strengths. It can be proved that the cost is near to same or even less than the cost of wired network. Major cost saving is achieved in terms of system installation, commissioning and maintenance of the system. It has been pointed out that at present the real time application needs to be analyzed with application specific testbeds at high cost[13]. We argue that if network protocol component is separated from application framework there will be large cost saving in application development as focus will be application specific requirements only.

2.4. Other Issues

Other issues are security, authentication and optimized energy consumption routing in wireless networks [2]. There is no doubt that these issue would be of importance depending upon the application requirement. This paper considers these issues as out of scope for this work.

3. Short Range Wireless Communication Test Bed for Railways

The system for migration to wireless communication is passenger amenity system installed at Indian railway stations. The system disseminates bogie information of the arriving train for passengers through coach indicators installed at each bogie position of the arrived train on the platform.

3.1. Present System

The deployed network is LED dot matrix display devices referred as coach indicators display (CI). These devices are installed on the railway platform, hanged from the ceiling or on poles. These displays are used for showing train number, coach type details like S1, AC I, PANTRY etc. for each of the bogie of arrived train on platform. There are 26 such coach indicator displays on every platform each 22 meters apart. All these devices are networked through RS485 multi-drop bus controlled through platform router. The router in turn is connected to the main system comprising of desk top machine and multiport serial RS485 bus controller.

The desk top machine is used for running Coach Guidance System (CGS) application. CGS GUI is shown in the figure 1.0. GUI allows operator to feed coach information for each bogie. The CGS GUI contains list of all probable coach types that might get attached to the trains. Another list contains coach number 1 to 26. Coach type placement information is received by station prior to the arrival of the train. This data is fed to the system by the operator. Operator selects train number and platform number of the arriving train and populates the list as per bogie placement information received. Bogie information of the selected train is displayed in the middle portion of GUI showing bogie selection against coach positions as shown in figure 1. The information is converted into a sequential ASCII file containing train number and bogie type with coach number. Upon pressing "Send to Display" button this file is transmitted via serial port connected to RS485 Bus driver. All coach display indicators receive the same file. Each coach indicator extracts train number and bogie type against each of coach number acting as device ID. After the train departs, operator presses “Clear Display” button which sends clear display message, all indicators returns to default mode displaying default message. The system uses duplex connectivity for enquiring coach display indicator about health and data displayed on the indicator.

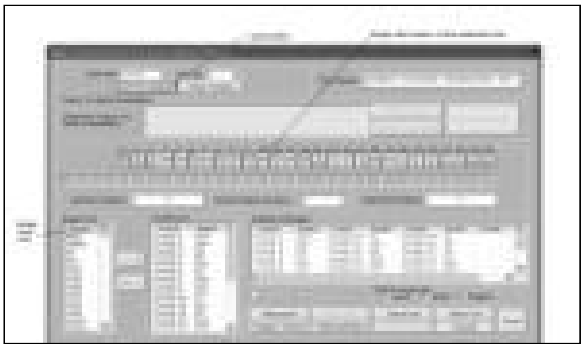

Fig 1 Coach guidance system GUI

3.2. Motivation

Present system is plagued by maintenance of data cables running besides devices carrying data to be displayed on indicators. Station contains many such systems making a cobweb of data and control cables on the platform. There is frequent breakage of data cables due to daily cleaning and maintenance of various departments of railway station. It is difficult to locate system fault and maintain the system performance.

4. Hardware and Software Design Issues

Figure no. 2 shows arrangement of the wireless devices on the railway platform. M is main controller interfaced to the desk top running CGS GUI via serial RS232 port. R1 and R2 are wireless routers. CI01 to CI26 are coach display indicators equipped with wireless trans-receivers. The network architecture is designed as three tier architecture. At first tier main controller acting as master controller of the network. The router act as local cluster controller at second tier and coach indicators treated as slave devices forms the third tier of this network. The coach indicators are 22 m apart. The length of the platform is 572m. The routers are positioned at 66m on both sides from the centre of the platform.

4.1. Hardware

A 32 bit RISC CPU integrated with radio peripheral is used to develop main controller M, routers R1,R2 and coach indicators CI01-CI26 radio interface module. The radio is 2.4 GHz, 802.15.4 compliant. Receiver sensitivity is -97 dBm and transmitting power set at +3dBm. Other features are MAC accelerator with packet formatting, auto-ack mechanism and security co-processor. Radio module at CI is interfaced with serial port to coach indicator display controller.

4.2. Network Layer

The network layer uses centralized control paradigm as is normal case with wired embedded device network. In this network architecture main controller acting as master controller carries out all network functionalities under his supervision and control. All network and data transfer events are controlled by master controller there by message collision is virtually avoided. A basic network layer is based on fixed topology and is designed on the top of 802.15.4 PHY/MAC layer. The network layer functionality includes establishing the network connectivity, data routing and data transport handling. Transport layer handles sequential file communication of wired network through packetized data communication and packet sequence control. Application layer uses services of network layer and transport layer for data transfer to destination devices. This minimizes the changes in the existing software and distributes the development cost on other applications. As regards with the issues raised in [13] with this facility a effort has been made to develop a application independent model which would allow the developer to treat network device as simple wired network device.

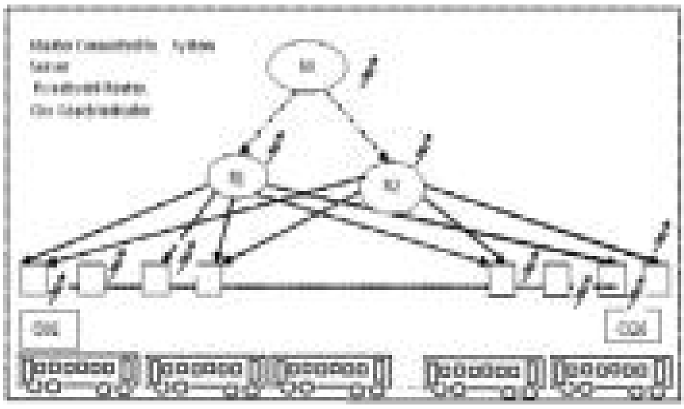

Fig 2 Arrangement of wireless devices on railway platform

4.2.1. Link quality, asymmetric links and robustness.

To bring robustness in network connectivity LQI is used as critical value to join devices in the network. These devices are joined under supervision of master controller if LQI satisfies LQI threshold value criteria. In figure no.2 if routers receiving LQI value with respect to particular CI is above threshold and CI receiving LQI value with respect to router is above threshold level then these devices are joined in the network. This ensures link quality control and symmetric link between these devices. In the above network two routers R1, R2 are used with position offset of two coach indicators from central CI on the platform. The range of radio is such that both routers can cover all coach indicators on the platform. However as expected LQI values will differ with distance of CI from router. CI is allotted to router based on LQI strength received by the router for that CI. Since care has been taken that LQI of the farthest CI is above threshold value for each router, all CIs will have communication route to master through both routers. This gives redundancy in the path towards master in case one of the routers fail, adding more robustness in network connectivity. Philosophy used herein is backed up by experimental work presented by [1] , [7], [12]. However the difference is we have used LQI threshold value at protocol design stage. This overcomes the problems discussed about irregularity of radio communication discussed in section 2.1.

4.3. *Data Transport Layer*

The transport layer provides different mechanisms for packet transmission.

NOACK packet: This is like UDP packet, receives no feed back from destination device.

AUTOACK packet: The device transmits the packet with hardware acknowledgment (HACK) request. If hardware ack is not received in specific time the packet is retransmitted. Max_retry is set to 3.

SOFTACK packet: The device transmits packet with end to end ack is request. The destination device issues specific SOFTACK (SACK) packet to the source device. If SACK is not received, packet is retransmitted with Max_retry set to 3.

4.4. *System Operation*

The network organization is dynamically formed. Routers (R1, R2) and End devices (CI01-CI26) broadcast hello packets after they are powered. Master controller (M) listens to routers' hello packets. Master issues JOIN command to the routers. Routers will accept JOIN command using received LQI value as described in section 4.2.1. Once these routers are connected to the master, they forward hello packets of neighboring CI devices to the master. Master prepares a routing database of these devices and assigns CI devices to router having higher value of LQI as primary router. Router having low LQI value with respect to same CI is assigned as secondary router having path towards the master. List of CIs attached to router is forwarded to corresponding router. The routers in turn issues JOIN command to CIs in the received list.

5. Results & discussion

Experimentation is conducted to verify the design stability as per design parameters and application requirements. Main focus was on reliable and robust communication between the devices and a cost effective solution.

5.1. *Setup*

Devices were setup at the railway platform as per topology shown in figure 1 at a height of around 4 m from the level of platform. The radio power was fixed at +3dBm, max packet retry value 3, packet payload 32 bytes, packet rate at 4 packets per seconds. The application required only master (M) to end device (CI) communication. This avoided problem of message collision and congestion. Devices were programmed to generate packets at rate of 4 packets per second for duration of 20 seconds for each experimental run. Three sets of experiment were carried out. Average of the three experimental set results are plotted for each parameter.

5.2. *Determination of LQI threshold value*

Experimental results are used to decide the threshold LQI value as connectivity metrics for devices in the network. This value is not particular to the field conditions presented for experimentation but can be used for all other application field situations.

As explained in section 4.2.1 LQI value is used as critical value to join the devices in the network. Table 1 shows LQI versus packet delivery efficiency with respect to NOACK; no feedback mechanism, HACK with auto-ack feature of the radio and SACK; software acknowledgment packet sent by the destination device for each of the data packet received. It was observed that packets with NOACK reach to 100 % efficiency at LQI value of 38. This value seems to guarantee 100 confidence level of message reaching to the destination even in the absence of feedback mechanism. Packets with auto ack and soft ack have reached to 100 % efficiency at LQI values lower than this. However the bandwidth overhead is significantly more at lower LQI values, which is expected as more number of repeat transmissions of data packet has to be made (refer table no.1). More bandwidth overhead also indicates increase in average packet delivery time.

Table 1 Variation of efficiency with LQI for different ACK schemes and respective bandwidth overheads

LQI	NOACK		HACK		SACK	
	Efficiency	Bandwidth Overhead	Efficiency	Bandwidth Overhead	Efficiency	Bandwidth Overhead
19	13.33	1.033	98.68	1.579	100	2.223
24	72.2	1.064	100	1.118	97.87	2.085
26	95.83	1.033	100	1.041	100	2.077
38	100	1.034	100	1.033	100	2.173
46	100	1.033	100	1.033	100	2.124
59	98.33	1.033	100	1.033	100	2.107
62	100	1.017	100	1.033	100	2.033
137	100	1.033	100	1.033	100	2.033

At LQI value 38, 100% packets are received without any feedback mechanism. At the same LQI value with feedback mechanism gives minimum BW overhead indicating there are no repeat transmissions required. This value can be safely used to as threshold LQI value which ensures confidence of 100% reliable communication between two radios.

Figure 3 shows LQI values received by router and CI devices with respect to each other plotted against coaches spaced at distance of 22 meters.It confirms that farthest CI (end node) has LQI value greater than 38 , injecting 100% confidence of success rate for the communication. LQI of the devices with each other do vary but the difference is not that significant which may lead to asymmetric link between these devices. The graph also confirms radio irregularity of short range radio trans-receivers.

5.3. *Packet Transmission Delays*

Average packet delay between master (M) and end device (CI) was found to be 14 ms at 250 kbps transfer rate, that means platform having 26 coaches (CI) would require 364 ms to update all CI's. In case of wired communication sequential file of size 320 byte was transferred at 9600 BPS, required 370 ms to transfer the file. The wireless media transfer did not incur additional delay due to individualized packet transfer to each device.

5.4. *Software and Hardware Changes*

A plug in module acting as wireless network connection device is introduced. This module is interfaced through serial port to the end device that is CI. An application independent network layer coupled with cross layer data transport mechanism was built for this module. The master uses same hardware with a serial interface with application GUI running on the desktop. The interface facilitated to read network topology and data communication with individual CI devices. The router is independent device which uses same hardware as of end device module.

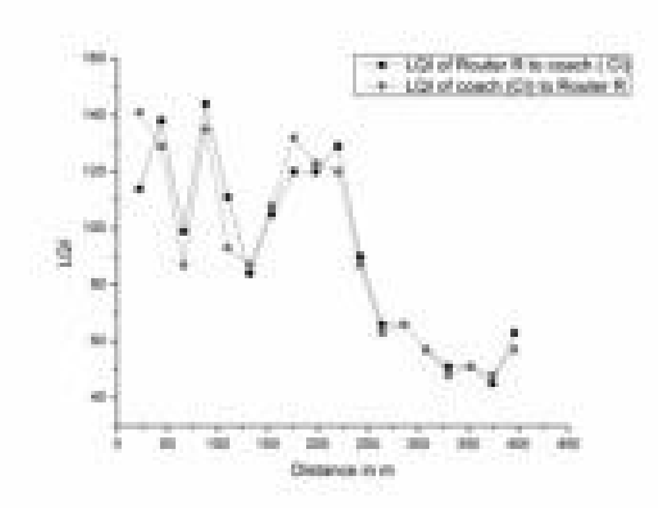

Fig 3 Radio irregularity of short range radio trans receiver

Software changes at server side was to deliver packet for each device in the network as against one sequential file for whole platform network which amounted to less than 5% change in the application software code. No change was done at coach Indicator embedded software side as the delivered data format was not changed.

5.5. Cost

A multiport RS-485 data disseminator at server side, platform RS-485 routers and RS-485 trans-receivers with coach indicator were replaced by wireless devices. These were replaced by Wireless master controller at server side, two wireless routers on platform, and wireless plug-in modules to be attached to each of the coach indicators. Total of 1500 m data cable with cable laying labor charges was saved. Around 20 % cost was saved with wireless devices in material and installation cost as compared to wireless network setup. The radio module development cost is not included in this however it is generic as same modules can be used for other applications as well. The issue raised in [13] is alleviated by developing application independent network and data transport mechanism as there is reusable software and hardware design which is a significant advantage.

5.6. Results

There is no such provision of guaranteed communication linking of end node on the basis of LQI or any other parameter to authors notice as discussed in section 4.2.1. Real time experimentation results have confirmed that for reliable and robust communication linkage between devices, introduction of LQI as link quality metrics greatly helps. The advantage of this mechanism is directly reflecting in 100 % communication efficiency and least bandwidth overhead. Another advantage is that it reduces possibility of asymmetric links in the network allowing user to view wireless network as normal wired network.

6. Conclusion

This paper presents a discussion of characteristics and challenges of short range wireless networks for real time application and in particular with case study of replacing wired network by wireless network. The real time industrial and commercial applications require QoS confidence level for reliable and robust communication. The contribution of this paper is introduction of LQI as connectivity metrics at network layer in the network setup mechanism. This has provided basis for connectivity confidence level to overcome radio irregularity and asymmetric link formation problems which are commonly found in the short range radio wireless networks. The results are presented to validate our approach leading to application and field condition independent network layer protocol. The real time implementation case for Indian railways presented here shows easy applicability and cost effectiveness of the solution. We intend to take up further consideration and adaptability of LQI at data transport layer for congestion avoidance and reliable data transport as future work.

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