Research Journal of Applied Sciences, Engineering and Technology 12(1): 63-68, 2016
DOI:10.19026/rjaset.12.2304
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: August 24, 2015 Accepted: September 11, 2015 Published: January 05, 2016

Research Article

Scheduling Approaches for Dedicated and Shared Timeslots for ISA100.11a: A Review

Abidulkarim K. Ilijan, L.A. Latiff, Rudzidatul Akmam Dziyauddin and Moneer Ali Lilo
Razak School of Engineering and Advanced Technology, Universiti Teknologi Malaysia,
Kuala Lumpur, Malaysia

Abstract: Wireless sensor communication has been an accelerating trend for industrial automation in controlling and monitoring processes. A variety of technologies has also emerged in fulfilling the industrial requirements. The ISA100.11a is an industrial technology to provide a vast range of industrial applications. Inevitably, scheduling schemes have a key role and direct impact on energy consumption and latency in the networks. To provide reliable scheduling, a number of schemes were developed to improve the network performance. In this review, we focus on the ISA100.11a technology and discuss several scheduling schemes for dedicated and shared timeslots. We present a technical overview of ISA100.11a with its advantages and disadvantages as guidance to developers and researchers. This study finally discusses the challenges posed by the scheduling techniques specifically in ISA100.11a.

Keywords: ISA100.11a, Bandwidth, industrial, scalability, scheduling, superframe

INTRODUCTION

The evolution of wireless technologies is anticipated to take essential changes in the area of industrial automation for the coming years. New wireless communication systems and technologies have taken a place of traditional wired control systems to connect the central hubs and sensors in the networks. The traditional wired systems that implemented in industries are able to provide high reliability, high speed and good services. However, these systems required more financial resources, spaces and infrastructure for installation. With the advancement of industries machinery, these traditional systems posed a new challenge in cable routing and maintenance (Gungor, 2009). The new wireless technologies are essentially as an alternative solution to overcome these challenges and offer various advantages to industries and other fields of life (Qureshi, and Abdullah, 2014).

Wireless networks have triggered the development of new standard protocols especially in industrial automation: Process control and its related applications. The first protocol of IEEE 802.15.4 standard (Chonggang *et al*., 2014; Man *et al*., 2013) has been proposed for ZigBee technology and has changed the wired based Fieldbus into new wireless network applications (Egan, 2005). Nevertheless, the ZigBee technology does not fulfill the requirements of the industrial applications. Considering this drawback, in 2007, another standard with the name of HART (Highway Addressable Remote Transducer) (Hart, 2014) communication foundation introduced WirelessHART in controlling the devices and measurement processes, specifically for the industrial systems (Zhu *et al*., 2012; Qureshi *et al*., 2014).

WirelessHART enables to provide better services through TDMA (Time Division Multiple Access) at the Medium Access Layer (MAC). In 2009, the International Standard of Automation (ISA) released ISA100.11a to cope the industrial applications with many features and a wide class of process control (ISA-100.11a, 2011; Quang and Kim, 2014). The ISA100.11a standard is an extension of IEEE 802.15.4 and supports different types of networks connectivity features compared with WirelessHART. It uses for deterministic applications and CSMA-CA (Carrier Sense Multiple Access with Collision Avoidance) mechanism in IEEE802.15.4-2011 (2011) for transmission of alarm, non-periodic, and retransmissions of failure messages. ISA100.11a is a standard of wireless mesh networks that offers secure and reliable wireless operations in alerting, monitoring, and controlling applications. This is the first standard of ISA100 family with the automation and management process including security coverage. In network systems and also in ISA100.11a, one of the most critical tasks is a real-time scheduling.

Industrial wireless technologies need specific optimized features, such as energy consumption, reliability and efficient transmission delivery without delay. The scheduling approaches are used to determine the channels in the networks (Forouzan, 2013). Several surveys have investigated the scheduling solutions for the wireless network in industries (Chonggang *et al*., 2014;

Corresponding Author: Abidulkarim K. Ilijan, Razak School of Engineering and Advanced Technologi, Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia

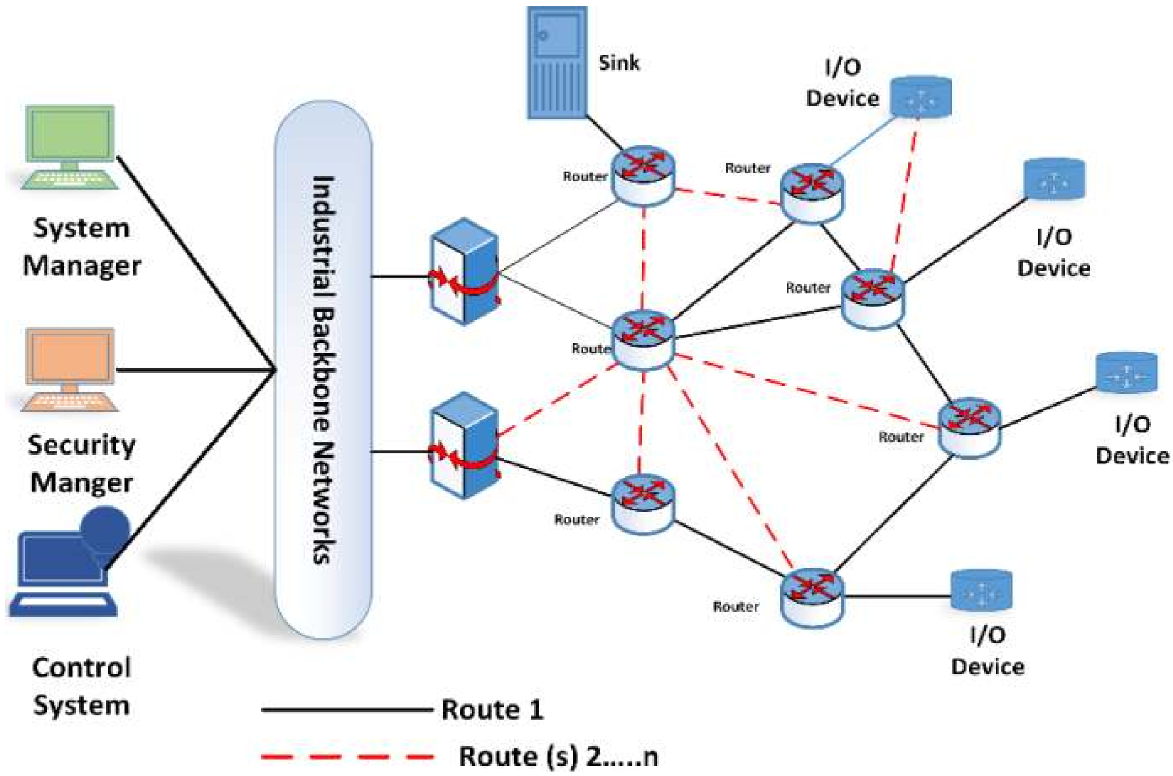

Fig. 1: An example of ISA100.11a network

Yigitel *et al*., 2011; Kumar *et al*., 2013). The surveys have a limited contribution on the scheduling techniques for both dedicated and shared timeslots cases. Therefore, in this study, our main focus is on the scheduling approaches for dedicated and shared timeslots and also to emphasize the key properties in designing an optimal time division multiple access protocols. In this review, the comparison of scheduling approaches, which are based on channel interference, synchronization, latency and communication patterns, is presented.

A technical overview of ISA100.11a: The ISA100.11a standard (Anon, 2011) offers secure and reliable wireless communication for different operations such as monitoring, alerting and loop controlling in industries. There are two types of networks:

- With backbone routers
- Without backbone routers

Both categories consist of different components in the networks, such as security manager, backbone routers and field devices. The system manager duty is to provide a policy-based control for network monitoring and runtime configuration and also to check operations and performance. On the other hand, the security manager performs security services between the ISA100.11a plant and field networks. The backbone routers are used to handle external networks, transmit ISA100.11a compliant packets and communicate with other networks. The ISA100.11a protocols are scalable for star and mesh topologies and can operate at 2.4-GHz band (Man *et al*., 2013). There are 16 channels (from 11 to 26) based on the IEEE 802.15.4 physical (PHY) layer, where Channel 26 is an optional in ISA100.11a. The media access control of ISA100.11a supports the TDMA and CSMA/CA mechanisms. The TDMA offers ISA100.11a with dedicated time slots on guaranteeing the data transmission without collision.

The dedicated time slot is purposely designed for predictable and regular traffic on satisfying Quality of Service (QoS) for industrial applications. ISA100.11a also supports slotted and slow channel hopping and hybrid methods. Each timeslot is based on the slotted channel hoping and operates on different radio channels for a singular transaction. The ISA100.11a network is scalable and can support a number of devices. The extended industrial wireless sensor network standards are, namely, ZigBee Pro (Chonggang *et al*., 2014), IP500 (Detection *et al*., 2014), WirelessHART and ISA100.11a (Hayashi *et al*., 2009).

The ISA100.11a standard is integrated with IEEE.802.15.4 at the physical layer and shares the same structure of frame. But, ISA100.11a uses its own (Fig. 1) scheduling methods at the IEEE802.15.4 MAC layer. Figure 2 shows the ISA100.11a architecture for the industrial wireless networks.

Table 1: A comparison of ISA100.11a and IEEE802.15.4

Comparison	ISA100.11a	IEEE802.15.4
Layers	Specifies an extended MAC layer of IEEE802.15.4, network and transport layer	Specifies for MAC and PHY layers
Manager address assignment	Dynamic assignment	Fixed assignment
Timeslot durations	Fixed to 10 or 12 ms	Flexible: one duration per network
Time measurement	International Atomic Time (TAI)	Coordinated Universal Time (UTC) TAI (alternative)
Superframe structure	Not specified	Yes
Frequency hopping	Slotted, slow and hybrid channel hopping	Adaptive Frequency Hopping(AFH), Adaptive Frequency Switching (AFS) and Timeslot Hopping(TH)
System management	Centralized, distributed, but not specified	Hybrid, centralized and distributed

Table 2: Advantages and disadvantages of ISA100.11a

No	Advantages	Disadvantages
1	Flexible	Complex
2	Support multiple protocols	Lack of interoperability
3	Open standards	Need expensive devices
4	Support multiple applications	Incompatibility
5	Reliable (error detection, channel-hopping)	Need superframe
6	Determinism (TDMA, QOS support)	Need more bandwidth
7	Provide security	High latency

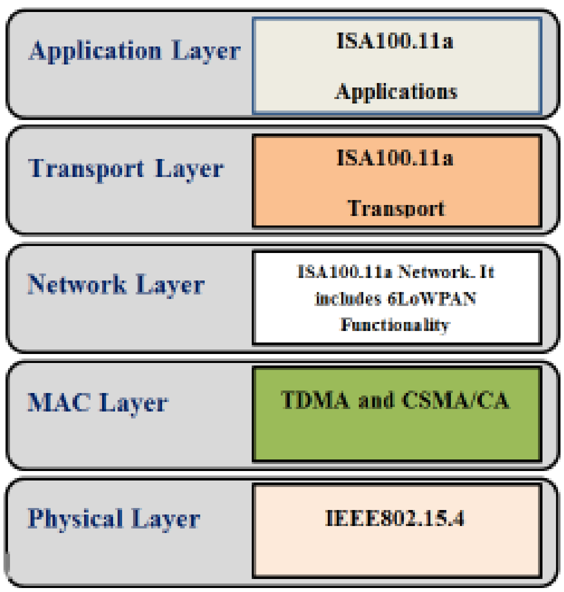

Fig. 2: The ISA100.11a architecture for industrial wireless sensor networks

The ISA standard is envisioned for industrial sector whereby it can provide efficient communication by implementing software modules to minimize the collisions of messages and provide security and latencies for data transmission. ISA100.11a includes the CSMA/CA protocol at MAC to further increase the performance and prevent packet collisions. ISA100.11a supports a number of features at the MAC and PHY layers and can support up to 16 and 64 bits for the addressing schemes. On the other hand, the IEEE 802.15.4 requires a low data rate approximately 250 kbps and specifies the maximum size of packet at the physical layer is 127 bytes. Table 1 shows the comparison of ISA100.11a and IEEE802.15.4 standards.

Advantages and disadvantages of ISA100.11a: There are many features of ISA100.11a in industrial sensor networks. As mentioned previously, the main target market of this standard is industrial automation and control applications. The standard encompasses power management capabilities at the physical layer and it has IEEE 802.15.4 with a DSSS/FHSS (Direct Sequence Spread Spectrum/Frequency-Hopping Spread-Spectrum) modulation. The MAC layer is based on the TDMA and CSMA-CA features with 16, 64 and 128 bit addressing schemes. Furthermore, the ISA100.11a standard is scalable with medium robustness and achieves high link reliability. It is self-organizing with end-to-end reliability that supports an enhancement in the security mechanism and mobility in the networks. In addition, the standard supports IPv6 (Workshops, 2008) based connectivity and delay-sensitive applications. It supports multicast transmission and large-scale networks with reliable broadcasting. The standard also has capabilities of energy consumption for battery-powered devices (Proakis and Salehi, 2008).

With many advantages, ISA100.11a has high implementation complexity for a complete protocol stack and need more costly devices in the networks. Another disadvantage is that ISA100.11a has a lack of interoperability with other IEEE 802.15.4 standards. From the developer point of view, this phenomenon refers to incompatibility with a deployment of low cost and rate.

A real-time scheduling (Forouzan, 2013) is one of the important tasks in the presence of low-rate transmission in ISA100.11a. To ensure a successful message delivery, periodic and sporadic messages must be calculated with high accuracy. A superframe can be specified as a group of timeslots repeated periodically and low link are then assigned to these superframes.

Many performance parameters determine the structure of the superframe. For examples, the latency sets with low data rate yields a short period and the increment of bandwidth utilization can lead to energy consumption. On the other hand, a long period leads to a high latency and low digital bandwidth causes less concentrated allocation for digital bandwidth. To tackle these issues, different types of scheduling approaches have been proposed and some of them are discussed in the next section. Table 2 shows the advantages and disadvantages of ISA100.11a.

LITERATURE REVIEW

Many scheduling approaches (Dinh and Kim, 2012; Dewanta *et al*., 2012) have been proposed in the wireless sensor networks in order to provide new scheduling algorithms for industrial technologies. Dinh and Kim (2012) proposed a priority CSMA-CA approach by adopting ISA100.11a and considering the backoff procedure and priority setting. In this scheme, ISA100.11a used a deterministic property of TDMA at the MAC layer for industrial applications. In this scheme, authors defined a 10-ms timeslot and each time slot contains only one ACK and transmission. The CSMA/CA in ISA100.11a offers a maximum bandwidth and operates better with a priority setting. The authors claimed that the scheme is suitable with time synchronization accuracy and the usage of priority setting can reduce the queuing delay on accessing the channel. Moreover, the scheme achieves a good network bandwidth utilization and capables in managing the transmission error. Thus, a high number of priority level resulted to less collision and better bandwidth in the networks.

Zhao *et al*. (2009) suggested a graph generation approach to present the graph as a minimum number of hops between source and destination. The graph is based on the shortest path algorithm, which is installed to render the networks with joining order. It is a multipath routing protocol, where the network manager has resources to generate the routings for the whole network and every node. The authors claimed that if the network adopts CSMA/CA, it leads to a contention at every link between nodes. To address this issue, the graph seems to be the best solution. Because of deterministic timeslot scheduling in ISA100.11a, TDMA does not refer to the shortest graph arrived towards the destination. The simulation results demonstrated that the algorithm in Zhao *et al*. (2009) is reliable and stable and efficient in terms of throughput and data delivery. Still in different situations, this kind of solutions have some failure, for instance, when the source node selects next hop from the routing table as their decision is based on the statistical properties of links and neighbors.

Chung *et al*. (2010) proposed a scheduling scheme based on a minimum delay graph routing. In this approach, authors used dedicated time slot, where the source sends the message via sink node in a multi-hop manner. The scheme consists of a monitoring system for fire detection, where the ISA100.11a standard suggests TDMA based MAC protocol and divides one superframe into many timeslots. This typically provides reliability while mitigating the interference. The authors claimed that through proposed minimum delay graph, the time slot scheduler minimizes the network delay and maximizes the throughput. In addition to that, the sleep phase of a node is able to work without compromising the reliability. This scheme is found to be a better option for emergency applications; sensing and controlling the communication quickly and effectively.

Recently, Nhon and Kim (2014) proposed two scheduling approaches for shared timeslots in the ISA100.11a networks. The first approach is TAMS (Traffic Aware Message Scheduling) used traffic information to categorize the devices in groups. This grouping is used in the scheduler decisions related to the cycles for data transmission, bandwidth utilization and collisions avoidance. The second approach is used for contention window and fixed with 192 microseconds for ISA100.11a specification when the probability of collision in the network exceeds a certain threshold. The results showed that the proposed schemes are efficient in terms of average end-to-end delay and probability of successful data delivery in the networks. Even though the algorithms are easily implemented for new devices, these algorithms suffer with certain limitations. This is because the algorithms are only able to work with star topologies and less effective in mesh topologies.

Shen *et al*. (2014) proposed a new medium access protocol for ISA100.11a and WirelessHART on addressing the latency issues in the industrial wireless sensor networks, particularly for critical traffic environment. The main feature of this scheme has used the initial and final parts of traditional timeslots. A high priority data transmission alerts the devices through signals about its occurrence whilst the devices with low priority will then hold their transmission. During the network operations, the high priority packets would hijack the bandwidth from low priority packets. This technique is anticipated for future standards and not suitable for current WirelessHART standard.

Miyazaki *et al*. (2012) proposed an adaptive channel diversity scheme in ISA100.11a for industrial wireless networks. This scheme is deliberately to improve the wireless communication in terms of reaching the reliability of industrial applications. The proposed approach replaced the frequency channels and selected the channels with no interference from other wireless systems. This scheme is found effective in a long interference and noise cycle.

Other researchers, Shin and Rezha (2012), developed a Controller Area Network (CAN) extension with ISA100.11a for industrial sensor networks. CAN protocols are serial bus protocols and primarily for message transmission. CAN protocols use a technique called CSMA/AMP (Carrier Sense Multiple Access with Collision Detection and Arbitration on Message Priority). The ISA100.11a protocol is used to provide secure and reliable wireless operations. In this model, authors proposed a framework to interconnect CAN2.0A networks with the ISA100.11a wireless networks. A packet fragmentation and encapsulation is employed to forward the packets from the upper layer.

Table 3: Comparison of scheduling schemes

Scheme Characteristics	Dinh and Kim (2012)	Zhou *et al.* (2009)	Chung *et al.* (2010)	Nhon and Kim (2014)	Shen *et al.* (2014)	Miyazaki *et al.* (2012)	Shin and Rezha (2012)	Dewanta *et al.* (2012)
Objective	Better utilization of bandwidth, reduces queuing delay, better with transmission error.	Reliability and stability	Reduce end-to-end and round-trip delay	Success probability and end-to-end delay	Latency	Reduce system latency and interference	Analyze delay charchtersitcis of ISA100.11a with CAN protocols	Improved data delivery and reliability
Metric	Time window	Hope count	Hope count	Mapping, Hope count	Degree	Publish rate	Packet encapsulation and fragmentation	Time window
Multiple Superframe	Yes	No	Yes	Yes	No	Yes	No	Yes
Redundancy	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Implementation	Yes, algorithm and simulation test	Yes, algorithm and simulation test	Simulation based	Yes, algorithm and simulation test	Test bed	Test bed	Simulation based	Simulation based

In this model, the distributed control system contains many distributed control units and connected with the CAN protocol networks for communication. The field devices are connected with a gateway and communicated through the ISA100.11a wireless networks. The simulation results in this research showed the delay characteristics of a hybrid network of CAN-ISA100.11a.

Dewanta *et al*. (2012) introduced a message scheduling scheme for dedicated time slots of ISA100.11a. In this approach, a superframe is designed with periodic real-time messages. The superframe is divided into dedicated time slots and responsible to send periodic real-time messages. On the other hand, the shared time slots are responsible to send alarm, sporadic and retransmitted messages. All real time messages are classified into low and high traffic scheduling. The author claimed that this approach is feasible for message scheduling. Table 3 shows the comparison of the scheduling schemes in industrial wireless sensor network, as previously discussed.

DISCUSSION

Different standards have been implemented to support the industrial wireless communication. In this study, we discussed ISA100.11a as the most appropriate standard for low-rate and low-power resource constrained devices. The standard has many features that turned it as an industrial solution, which offers various applications. With many advantages, the standard has still suffered from different challenges. There are different applications needed to fulfill the industrial requirements for automation and controlling and different algorithms are used to improve the network performance. Any new solution needs to use some parameters especially for scheduling, as examples, a degree and deadline used to determine the channels and links. Different devices with different fix periods are grouped into one superframe.

The efficient scheduling is referred to a pool of resources are allocated to be served and can provide end-to-end transmission scheduled with redundancy in the networks. The scheduling algorithm classified the information flow from devices to gateway as an uplink. Based on the literature, we analyzed two trends in achieving the scheduling objective. The first is related to the scheduling itself and the second trend concerned with improving specific characteristics, such as latency, channel usage and reliability. Based on the literature review, we can verify that the message scheduling approaches for dedicated and shared timeslots in ISA100.11a is a rich field with a variety of solutions and algorithms; on account of verity of industrial applications. These solutions are proposed to improve the standard reliability using multiple paths and by controlling the temporal redundancy. The ISA100.11a has more advantages compared with other standards, but need some attention to improve the current scheduling approaches and hence enhance the network performance.

CONCLUSION

Over the last few years, we have noticed about the success of industrial wireless sensor networks applications for automation. However, every standard is designed to provide cost effective and efficient transmission for low power capabilities and small size sensor devices. The ISA100.11a standard arose to extend and promote multi-hop communications and for large area monitoring. In this study, we reviewed most recent and significant scheduling approaches for dedicated and shared timeslots for ISA100.11a. The performance of large scale networks is more affected through the scheduling and routing algorithms overhead. The key issue is scalability for choosing the algorithm for ISA100.11a. Additionally, we highlighted the advantages and disadvantages of ISA100.11a. In this study, we also highlighted the main points on designing an efficient scheduling algorithm. We can conclude that the design of efficient solutions for diverse industrial wireless sensor network scenarios will demand more time despite the efforts made so far.

REFERENCES

Anon, 2011. Standard: ISA100.11a, Wireless Systems for Industrial Automation: Process Control and Related Applications.

Chonggang, W., J. Tao and Z. Qian, 2014. ZigBee Network Protocols and Applications. Auerbach Publications, CRC Press, Taylor&Francis Group pp: 157.

Chung, Y., K.H. Kim and S.W. Yoo, 2010. Time slot schedule based minimum delay graph in TDMA supported wireless industrial system. Proceeding of the International Conference on Computer Information Systems and Industrial Management Applications (CISIM, 2010), pp: 265-268.

Detection, S. *et al*., 2014. IP500 ® -the Standard for Wireless Smart Devices in Building Automation. About the IP500 ® Alliance, Berlin, pp: 1-2.

Dewanta, F., F.P. Rezha and K. Dong-Sung, 2012. Message scheduling approach on dedicated time slot of ISA100.11a. Proceeding of the International Conference on ICT Convergence (ICTC, 2012). Jeju Island, pp: 466-471.

Dinh, N.Q. and D.S. Kim, 2012. Performance evaluation of priority CSMA-CA mechanism on ISA100.11a wireless network. Comp. Stand. Inter., 34(1): 117-123.

Egan, D., 2005. The emergence of ZigBee in building automation and industrial control. Comput. Control Eng. J., 16(2): 14-19.

Forouzan, B.A., 2013. Data Communications and Networking. Retrieved from: http://www.ncbi.nlm.nih.gov/pubmed/21843847.

Gungor, V.C., 2009. Online and remote motor energy monitoring and fault diagnostics using wireless sensor networks. IEEE T. Ind. Electron., 56(11): 4651-4659.

Hayashi, H., T. Hasegawa and K. Demachi, 2009. Wireless technology for process automation. Proceeding of the IEEE ICROS-SICE International Joint Conference. Fukuoka, pp: 4591-4594.

IEEE802.15.4-2011, 2011. IEEE Standard for Local and Metropolitan Area Networks-Part 15. 4: Low-Rate Wireless Personal Area Networks (LR-WPANs). Retrieved from: https://standards.ieee.org/findstds/standard /802.15.4-2011.html.

ISA-100.11a, 2011. Wireless Systems for Industrial Automation: Process Control and Related Applications.

Kumar, M., I. Gupta, S. Tiwari and R. Tripathi, 2013. A comparative study of reactive routing protocols for industrial wireless sensor networks. In: Singh, K., A.K. Awasthi and R. Mishra (Eds.), QSHINE, 2013. LNICST 115, Springer, Berlin, Heidelberg, pp: 248-260.

Man, L.A.N., S. Committee and I. Computer, 2013. IEEE Standard for Local and Metropolitan Area Networks - Part 15. 4: Low-Rate Wireless Personal Area Networks (LR-WPANs) Amendment 4: Alternative Physical Layer Extension to Support Medical Body Area Network (MBAN) Services Operating in the 2360 MH-2400 MHz Band. IEEE Standards Association, Retrieved from: https://standards.ieee.org/about/get/802/802.15.htm l.

Miyazaki, M., R. Fujiwara, K. Mizugaki and M. Kokubo, 2012. Adaptive channel diversity method based on ISA100.11a standard for wireless industrial monitoring. Proceeding of the IEEE Radio and Wireless Symposium (RWS, 2012), pp: 131-134.

Nhon, T. and D.S. Kim, 2014. Real-time message scheduling for ISA100.11a networks. Comp. Stand. Inter., 37: 73-79.

Proakis, J.G. and M. Salehi, 2008. Digital Communications. 5th Edn., McGraw-Hill, New York.

Quang, P.T.A. and D.S. Kim, 2014. Throughput-aware routing for industrial sensor networks: Application to ISA100.11a. IEEE T. Ind. Inform., 10(1): 351-363.

Qureshi, K.N. and A.H. Abdullah, 2014. Adaptation of wireless sensor network in industries and their architecture, standards and applications. World Appl. Sci. J., 30(10): 1218-1223.

Qureshi, K.N., A.H. Abdullah and R.W. Anwar, 2014. Wireless sensor based hybrid architecture for vehicular ad hoc networks. TELKOMNIKA (Telecommun. Comput. Electr. Control), 12(4): 942.

Shen, W., T. Zhang, F. Barac and M. Gidlund, 2014. PriorityMAC: A priority-enhanced MAC protocol for critical traffic in industrial wireless sensor and actuator networks. IEEE T. Ind. Inform., 10(1): 824-835.

Shin, S.Y. and F.P. Rezha, 2012. Extending CAN protocol with ISA100.11a wireless network. Proceeding of the International Conference on ICT Convergence (ICTC, 2012), pp: 472-476.

Workshops, I.S.P.T., 2008. IPv6 Routing Protocols.

Yigitel, M.A., O.D. Incel and C. Ersoy, 2011. QoS-aware MAC protocols for wireless sensor networks: A survey. Comput. Netw., 55(8): 1982-2004.

Zhao, J., Z. Liang and Y. Zhao, 2009. ELHFR: A graph routing in industrial wireless mesh network. Proceeding of the IEEE International Conference on Information and Automation (ICIA, 2009), pp: 106-110.

Zhu, X., T. Lin, S. Han, A. Mok, D. Chen, M. Nixon and E. Rotvold, 2012. Measuring wirelessHART against wired fieldbus for control. Proceeding of the IEEE International Conference on Industrial Informatics (INDIN), pp: 270-275.