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To cite this article: F Anwar et al 2017 IOP Conf. Ser.: Mater. Sci. Eng. 260 012025

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Network-Based Real-time Integrated Fire Detection and Alarm (FDA) System with Building Automation

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Abstract. Fire alarm systems have become increasingly an important lifesaving technology in many aspects, such as applications to detect, monitor and control any fire hazard. A large sum of money is being spent annually to install and maintain the fire alarm systems in buildings to protect property and lives from the unexpected spread of fire. Several methods are already developed and it is improving on a daily basis to reduce the cost as well as increase quality. An integrated Fire Detection and Alarm (FDA) systems with building automation was studied, to reduce cost and improve their reliability by preventing false alarm. This work proposes an improved framework for FDA system to ensure a robust intelligent network of FDA control panels in real-time. A shortest path algorithmic was chosen for series of buildings connected by fiber optic network. The framework shares information and communicates with each fire alarm panels connected in peer to peer configuration and declare the network state using network address declaration from any building connected in network. The fiber-optic connection was proposed to reduce signal noises, thus increasing large area coverage, real-time communication and long-term safety. Based on this proposed method an experimental setup was designed and a prototype system was developed to validate the performance in practice. Also, the distributed network system was proposed to connect with an optional remote monitoring terminal panel to validate proposed network performance and ensure fire survivability where the information is sequentially transmitted. The proposed FDA system is different from traditional fire alarm and detection system in terms of topology as it manages group of buildings in an optimal and efficient manner.

1. Introduction

Fire detection process for trading and housing places is a main requirement to reduce destruction of personal property due to fire incident both natural and induced. Combining the network with controller approach, an innovative improvement has been made in building automation. The real-time surveillance system not only monitors the building automation ministrations but also control the FDMS by gathering, observing and storing related information. Among the basic technologies, networking had been used for improved building automation controller construction. Research notes that the concept of networking based controller used in many building automation process are more effective in fire detection and protection [1-3].

It has been noted that, the integration of networking, detection modules, sensors and a server work as a system to transmit data for fire detection. The communication method of exchanging information takes place via a digital communication medium. The exclusive design of the detectors spot the exact region of the fire effortlessly. Also, the workstations are organized to monitor the fire detectors at regular
intervals in order to estimate any repair needed in the system. Most of the network-based fire detection systems are recently manufactured and traded with their proprietary network protocols [4-6].

The design criteria of any fire alarm systems; should differentiate between a false and genuine alarm, allowing quick rescue and implementing accurate evacuation process, thus aiding the fire defenders. Furthermore, the fire alarm system should have the ability to reduce energy intake, in comparison with the existing systems. Hence, an intelligent fire system is required. These innovations will make up a new openings and occasions in marketing fields for fire detection, safety and alarm systems [7-8]. Researcher also designed fire detection system unified with smoke detection sensors, health monitoring devices, display module, wireless communication modules, multi detectors sensors, distant approach through networking module, temperature sensors and liner heat sequences monitoring system. The main ideology to combine these techniques is to develop trustworthiness, reduce the occurrence of fake alarm, discriminate between a natural or induced fire smoke and most importantly increase the life of property by fire protection systems. The conventional fire detection system requires much improvement and plenty of research nowadays to increase detection sensitivity of any sign of smoke at a particular area [9-11]. Similarly, the cost-effective sensor network system have more advantages then conventional to enhance duribility and reliability of an intelligent automation system [13].

A system has also been developed with wireless sensor based neural-network for fire detection. The neural-network was used to increase the life expectancy of the network. The researcher used simulation process to show the performance [14]. They also validate that the simulation process is efficient to reduce communications between sensor nodes. Another research group developed grey-fuzzy controller based neural-network to detect the fire detection in the Tibet region. The design was developed to monitor signal values of fire detection sensors to calculate the value of smoke, temperature and CO$_2$ density in air during the detection period, where the 30 seconds dealy detection technique was used. Finally, the data was used as prediction result input to ANFIS system to determine the detecting probability [15]. A communication network of a system was proposed to extend by an intermediate-layer or dependability layer. The layer should be transparent to operate on seamless intricated network. Thus, the group addressed reliability in terms of fault tolerance. They basically offered a redundant network in the system and named as heartbeat mechanism. Where the system acknowledgment and specific message format will hold the safety requirements [16]. A Network feedback based Internet of things (IOT) system and method was proposed for home and small business. The main motive was to connect, control and monitor more than one appliances together. The proposed system is used to understand electrical consumption, make decisions on fault detection, prompt to save energy, upgradation of the system, Internet based monitoring and alarm for the system as well as prevention of device over-heated or frozen, damaged device detection, possibility of fire losses and loss of life. The proposed system also includes Internet communication based software and data communication, hardware interfaces on safety issue in communication line and optional wireless outlet [17].

A stand-alone security system was transformed into intelligent network based on computer controlled automatic building automation system. The purpose of the research was to design a pilot models for security using wired network technology. web based virtual instrument was introduced to monitor and control the base from long distance. It was claimed that, they can be re-usable with little customization and increasing some more nodes. Though the system shows more potential but it is not reliable in the long run, because of maintenance and non-automatic plug and play service [18]. Another research group proposed wirelessly node detection using FPGA based management. It was a Zigbee technology using LabVIEW software. LabVIEW developed FPGAs are used for high performance system, where this system will be highly reliable [19]. An intelligent alarm system was designed with photoelectric materials to detect smoke and temperature. The system use AT89C51 unit as hardware control and monitoring. The controller unit converts the analogue signal to digital signals and produce machine output. The system is simple and low cost [20]. Wireless Sensors Network for FDS also became more popular because, detection message will be delivered through wireless sensors. The wireless sensor
nodes include catalytic gas sensors, controller and wireless transceiver using BACnet protocol but the weakness is noise and false alarm. To overcome this problem controller area network (CAN) was develop through a radio protocol known as wireless protocol [21-23]. A system was developed to reduce the false alarm in the train. The system was developed by smart sensors and microcontroller. It will automatically detect fire and use mobile network to share information. The nodes use pattern matching system where a predefined set of rules were use as packet of traffic. To reduce false alarm, the signals are re-analysed with the predefined packet of traffic and detect the signal as bad traffic. But, the main drawback of the network is that, the ratio of the false alarm depends on the performance of detection engine. To reduce this problem signature-based traffic method was developed [24-25].

Researcher also developed UV and infrared stereovision sensors to detect fire in low visibility range. These sensors can be used for long term fire detection system using 3D coordination effect of fire. Visual servo system was used to target the fire location and place the suppuration module towards the fire to remove fire immediately. The system perfectly worked on visibility condition of 1.62 meter. The surrounding environment was developed with simulated wind and smoke effect [26]. A probabilistic classification method was developed using thermal detection method. The algorithm automatically locates fires by thermal imaging technique, where visibility is zero. This algorithm was also established through test data set [27]. Again, a signal traffic management system for FDS was proposed for smart cities. Where, a robust fire detection method was proposed using dictionary method. The method computes each patch using linear SVM [28-31].

Optical fiber sensors are proven to be used in industrial applications because of long durability. Common distributed sensors performance is exploited through optical sensors because of fire detection special resolution. The sensors can detect long distance with higher accuracy [32]. A distribution network using optical fiber for close room environment is highly effective for fire detection system. The problem of these sensor was that, it can work only in close room. Though, the method demonstrated that it represents a robust and reliable technique to localize the fire place [33]. The communication system for fire detection system should be more reliable and durable. The system will be a bi-directional highspeed distribution network and the data will be carried out through data bus signal [34-35].

For optical fiber network all possible network combination is suitable because of high data transfer rate. In the next generation all network architecture designing on optical fiber, however P2P network are different from each other. For AON (active optical network) and wavelength division multiplexing passive optical network (WDM PON) fiber is the best choice. Even future 5G network also designing on fiber network due to the data transfer capacity. Also, cloud based network excess relay on optical fiber network [36-38].

The proposed framework of powerful fire alarm detection system depends upon Ring Topology. In this work, the focus is set to develop an efficient fire alarm detection system, applying a topology which depends on algorithmic approach. This framework enlightens currently available process of powerful fire detection system by minimizing the time to activate an alarm system. Moreover, by integrating the FDA system into the buildings, it will allow the system to react to variations in real time, thus able to generate alarm during the state of an emergency.

### Table 1. Summary of the important research developments.

| Methods                  | Years | Advantages                                                                 | Disadvantages                                  |
|--------------------------|-------|-----------------------------------------------------------------------------|-------------------------------------------------|
| Network feedback         | 2014  | 1. connect, control and monitor more than one appliances together through IOT.| 1. Constant monitoring and services is required. |
| based IOT                |       |                                                                             |                                                 |
| Wired Building           | 2015  | 1. pilot models with wired                                                 | 1. Mainte-nance required.                      |
| Method                                      | Year | Advantages                                                                                      | Drawbacks                                                                                       |
|---------------------------------------------|------|-----------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| Automation                                 |      | 1. Network-based instrument.  
2. Web based instrument.                        | 2. Automatic nodal updates not possible.                                                        |
| Network-based FDS via CAN                  | 2004 | 1. Very short response time.  
2. Direct data accusation for accuracy.         | 1. Data receive directly from the fire detectors any interruption means system loss.            |
| FPGA based smart system.                   | 2016 | 1. Smart system.  
2. Auto update.                                 | 1. Use for stand-alone system.                                                                 |
| BAChnet-based FDS                          | 2014 | 1. Monitoring system using MS/TP protocol.  
2. reference model is operated by wireless-BACnet for flexibility. | 1. Signal is directly dependent upon the traffic load.  
2. Inter-operability of different vendors’ field devices makes problems. |
| Address-able FACS                          | 2015 | 1. Broad range of device connecting capabilities.                                              | 1. Standard capacity of maximum 127 points.                                                     |
| Dedicated Computer Controlled system        | 2016 | 1. Added power, Internet connectivity and remote service capabilities                          | 1. Failure of dedicated computer or connection problem can fail the system.  
2. Required maintenance.                    |
| Address-able VAD (Visual Alarm Device)     | 2010 | 1. Visual Alarm Device.                                                                      | 1. For a small plant.  
2. Extension not possible.                    |
| Pattern matching process                   | 2015 | 1. Use predefine pattern matching process.  
2. Signature based traffic.                   | 1. The performance depends on detection engine.                                                  |
| Mechatro-nic approach                      | 2016 | 1. Autonomous fire-suppression module was used.  
2. Versatile device addable.                  | 1. The autonomous system was used is expensive.                                                 |
| Optical fiber sensors                      | 2014 | 1. Long durability.  
2. Long distance detection.                    | 1. Problem of hot air.                                                                         |

2. Network-Based Fire Detection System

As it is known that a number of existing technologies are implemented in the past for effective fire detection system in a real-time environment which faces a major drawback in the transmission of data over a large distance. A long-distance data transmission using normal communication cable can lead to a drop-in signal, hence making it inconvenient for long distance data transfer. If all the different buildings are made to connect to one network, and by implementing a suitable network topology, that will be able to take the shortest path to transmit the monitored data, then the stability of the system can be enhanced. The network topology selected in this work is based on the prime interest which is being able to connect different buildings in one network. From many available network topologies like bus topology, star topology, ring topology, mesh topology, tree topology, and hybrid topology, we have chosen the ring topology. In this situation as compared to others, since communication between long distance is the key factor in this work. The inter-building communication is normally done using
communication cable where signals tend to drop significantly over long distance data transfer. Fig. 1 shows a typical ring network topology setup. Here, a token or a tiny data packet is transmitted around the network and whenever there is a need to transmit a data packet, the device keeps the token for the next trip around and fixes its data packet to it. This set up makes it extremely easy to manage the peer to peer network. While the transmission is intended for a short distance, an effective and high quality communication is ensured. This set up is perfectly suitable to handle traffics of high volume in short distance. Furthermore, the ring topology uses dual rings as a backup in case of one link failure with less wiring.

![Figure 1. Ring topology setup.](image)

3. Proposed Algorithmic Approach of Fire Alarm Detection System

To upgrade the capability of currently running fire detection and alarm system for long distance, this algorithmic was proposed, to reducing noise and signal drop problem while delivering an authentic alarm in the network. Optical fiber and optical module were proposed in building nodes where internal sensors connection will be the same with normal network cables. By using optical network procedure during a crucial time, the fire affected buildings could be saved with minimum losses. A prototype simulation model system, based on real world situation (having the same parameters) was implemented / designed for fire detection system and fire alarm, as like, the FDA system screens sequence of buildings in a restricted area, such as in industrial environment, some buildings located closely in an area. All the buildings and CCR was connected to each other by means of a ring network. The framework would share the information in peer to peer method, connecting the remotely situated control panels. To supply an alarm signal and give proclamation of fire state, the panel connected in the network would produce alarm signal on network state to send information to the other panels or CCR. Because of signal analysis and signal conversion it may few times, But the real-time communication time depends on the number of connected building nodes. Considering this problem, the framework will work on shortage path calculation and proclaim its fire state to CCR. Again, if the communication is somehow interrupted the longest path will be considered. The shared information
work in a consecutive manner from one building to another. Fig. 2 illustrates the flow chart of the algorithm used in this work.

![Flow chart of proposed algorithm.](image)

**Figure 2.** Flow chart of proposed algorithm.

4. Fire Detection System with Ring Topology Building Automation System

In this following section, it is explained how the least and highest time is calculated in a building during a fire incident for different scenarios. The work conducted is intending to use three building blocks. Blocks A, B, and C are assumed to be situated in an industrial area. Each block is surrounded by six other buildings within a distance of 500 meters (as seen in Figure 3), fire alarm panels are affiliated to fiber optic converter to form ring topology when all buildings are joined in a group. The management of transmission between the buildings is made effortless through ring -based approach. The Block A consist of building number 1, 2, 3, 4, 5 and 6. Similarly, Block B and C consist of building numbers 7, 8, 9, 10, 11, 12 and 13, 14, 15, 16, 17, 18 respectively. These blocks are connected with Gytc8s single optical fiber 8-layer outdoor and its respective signal conversion module. The inter block ring network also can work if any inter block connection failure happens and signal will flow through any short or long possible way.
Central Control Room (CCR)

Bomba Station

Shortest path

Longest path

Addressable Fire Alarm System

Block A
Figure 3. Projected network topology for the buildings with the control rooms (CCR) and fire rescue department (Bomba Station) including Block A, Block B and Block C.
The buildings 5 and 6, 11 and 12, 17 and 18 were contacted in same network fashion by Gytcs outdoor use cable to share information in CCR loop network. The reason for selecting these buildings to be connected with the core is that they would have the shortest distance from the central control building and the fire rescue department in the network.

The core communication line connects control units and fire rescue department with rest of buildings in block. Building 6 in block A is in most immediate reach to the control unit. And for the fire rescue department it is 17. Distance of the control unit from the fire rescue department is about 500 meters as shown in Fig. 3. The fire alarm situation in the network is observed and monitored through communication among each other. They maintain contact with other buildings in blocks through Ethernet switch by using cate STP cable.

The function of the central control room (CCR) and fire rescue department is to supervise and regulate the communication. On the contrary when either CCR or fire rescue department is deviated from its function due to certain circumstances then still one can control it by alternative ways. Further, information can be sent or received among each other. This makes more persistent connection between topology of building and these control units. Under worst events where both control units fail, the buildings connected in a loop network can work as standalone network and during fire detection the loop network can perform their operation individually by switching local alarm or visual devices, sending information through passive proclamation gadgets, releasing the magnetic lock, AHU management, governing of sprinkler and elevator alarm declaration activation, releasing relatively non-secure door links, switching gas control unit, locking the highly secure area those are far away from fire detection place, CO2 gas unit interfacing and switching the main power module to off etc..

5. Discussion and result analysis

In this work JAVA script was used for coding and execution of the algorithm. The results of shortest and longest paths are discussed.

A case scenario is taken to understand how the FDA system works. It was assumed that building 2 caught fire in Block A as shown in Fig. 3, shortest time taken for sending signal to control room would be through building 1 to 6 to CCR.

In the same way, only using building 3 the longest path can send information to CCR. The short and long paths results are shown in table 1 and table 2 respectively. It is obvious that the longest path (B2, B3, B4, B5, B6, CCR) consumes more time than shortest path (B2, B1, B6, CCR). The topology of buildings frames out the reason behind the shortest path. Figure 4 and Figure 5 are showing the result of building 8 block A for the shortest path and the longest path calculation.

For shortest path calculation in block A when building 2 catches fire the shortest path has been calculated as a minimum number of buildings from affected building to control unit through B1 as shown in Table 1 and Figure 4. According to time calculation, it took 3 seconds to reach control unit where only two buildings are crossed from source to destination.

| No. of Path | Building Under Fire | Shortest Path To CCR | Distance Covered to CCR (Meter) | Time to Reach Signal (Second) | No. of Buildings Crossed |
|-------------|---------------------|----------------------|--------------------------------|------------------------------|--------------------------|
| 1           | Building 2          | B2, B1, B6 & CCR    | 1500                           | 3                            | 3                        |
Figure 4. Receiving signal from building no. 8 through shortest path to the Central Control room.

In the case of the longest path, the route from building B2 to CCR is through B3. Here the distance covered is 2500 meters and time to reach the destination is 5 seconds as shown in Table 2 and Fig. 5. The buildings crossed are 4 as compared to 2 in shortest path. Here if shortest path is not feasible due to some reasons then the communication can be completed by longest path.

Table 3. Shows the time and other parameters calculation of longest results in Block A.

| No. of Path | Building Under Fire | Longest Path to CCR | Distance Covered to CCR (Meter) | Time to Reach Signal (Second) | No. of Buildings Crossed |
|-------------|---------------------|----------------------|---------------------------------|-----------------------------|--------------------------|
| 2           | Building 2          | B2, B3, B4, B5, B6 & CCR | 2500                            | 5                           | 5                        |
Let’s suppose building 8 caught fire in block B as shown in Fig. 3. The minimum time required for the signal from building 7 to 12 can be calculated. In the same way pathways of 9 to 12 to Control room is estimated. shortest and longest paths results are shown in Table 3 and Table 4 and in Fig. 6 and Fig. 7 respectively.

In the case of block B if building 8 caught fire then the shortest path is from B7 to CCR where it took 5 seconds to send signals to control unit. The total distance covered is 2500 meters and number of building crossed is 5.

**Table 4.** Shows the time and other parameters calculation of shortest path results in Block B.

| No. of Path | Building Under Fire | Shortest Path to CCR | Distance Covered to CCR (Meter) | Time to Reach Signal (Second) | No. of Buildings Crossed |
|-------------|---------------------|-----------------------|---------------------------------|-------------------------------|--------------------------|
| 1           | Building 8          | B8, B7, B12, B5, B6 & CCR | 2500                            | 5                             | 5                        |
Figure 6. Receiving signal from building no.8 through shortest path to communicate with the Central Control room.

In the case of block B if building 8 got fire then the longest path is from B9 to CCR as shown in Table 4 and Fig. 7 where it took 7 seconds to send signals to control unit. The total distance covered is 3500 meters and number of building crossed is 7.

Table 5. Shows the time and other parameters calculation of Longest results in Block B

| No. of Path | Building under Fire | Longest Path To CCR | Distance Covered to CCR (Meter) | Time to Reach Signal (Second) | No. of Buildings Crossed |
|-------------|---------------------|---------------------|--------------------------------|-----------------------------|--------------------------|
| 2           | Building 8          | B8, B9, B10, B11, B12, B5, B6 & CCR | 3500                           | 7                           | 7                        |
Figure 7. Receiving signal from building no.8 through longest path to the Central Control room.

6. Conclusion and Future Work
To conclude, in this work, an advanced Fire Detection and Alarm (FDA) system is designed based on a robust network technology and tested with simulated network architecture. The simulation process shown an expected performance while working in proposed network tropology to send alarm to the central control room. In this system, it is required to place the fire detection location according to the arrangement of the distributed networking system as building location to analyse its performance. But, for the lab test building localization mechanism is considered with virtual device connection process. Therefore, the virtualization of designed workload makes the system appear more robust then usual. Therefore it requires further tests with more realistic scenario to ensure its fire protection capability and to compare the efficiency over other systems. To improve the fire detection systems of the buildings, we will also focus on control automated solution of predicting the fire behaviour in an efficient manner.

7. Acknowledgement
8. The Authors express their personal appreciation for the effort of Saiyara Shehnaz in proof-reading the paper. The authors gratefully acknowledge the financial support of IIUM Research Management Center (RMC) and Ministry of Higher Education Malaysia under Research Initiative Grant Scheme (RIGS) number RIGS16-084-0248.

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