Recent trend in wireless sensor network and its applications: a survey

Poonam Prasad
CSIR-National Environmental Engineering Research Institute, Nagpur, India

Abstract

Purpose – This paper aims to review existing wireless sensor network (WSN) setups in various domains, focusing on affordable WSN so that it can be effectively utilised in solving the environmental problems. WSN is being explored in many applications such as home security, smart spaces, environmental monitoring, battlefield surveillance and target tracking. WSN consists of a number of tiny, low-powered, energy-constrained sensor nodes with sensing, data processing and wireless communication components. Creating a WSN setup will make the monitoring system effective and in future, it will give a roadmap for solving some common societal problems.

Design/methodology/approach – Various research papers in the area of WSN have been reviewed on the basis of technologies and application on different fields.

Findings – WSN was found to be the most effective solution in areas which are less explored due their hazardous nature and are difficult to reach.

Originality/value – This review is based on research papers available and a recent trend in the area of WSN has been explored.

Keywords Environment, Wireless sensor networks, Algorithms, Mote, Nodes

Paper type Literature review

1. Introduction

The concept of wireless sensor network (WSN) started with the Smart Dust project in 1998. The basic component of a WSN is a sensor node composed of sensing, computation and wireless communication unit. A WSN consists of a large number of tiny, low-powered, energy-constrained sensor nodes with sensing, data processing and wireless communication components. Sensor nodes share small battery-powered devices whose batteries cannot be recharged with limited energy resources at the time of deployment. WSN was used as a platform for control and monitoring in many varied applications, from natural monitoring to ambient awareness, from military to surveillance and from industrial plants to domestic home environments and volcano monitoring (Yang and Cao, 2008; Papageorgiou, 2003; Stankovic, 2013). As an exciting area of research, WSN has been used in many applications such as home security, environmental monitoring, target tracing, etc. (Akyildiz *et al.*, 2002; Yick *et al.*, 2008). WSN technology standards and applications were studied by Lewis (2004); the focus was on the multidisciplinary research area where collaboration of user's domain experts, hardware designer and software developers were essential components for efficient implementation. The design of WSN for minimum consumption of energy was discussed in a paper by Heinzelman *et al.* (2002), where cluster routing was found to be an effective solution in reducing energy consumption and provided network stability; sensor nodes were divided into groups to form a cluster and each cluster had a leader known as cluster head (Abbasi and Younis, 2007). Sensor nodes also have the constraint of less storage and communication capability; it communicates in the network with the radio interface; WSN has necessary applications such as remote environmental monitoring and target tracking (Maraiya *et al.*, 2011). Network of sensor nodes observe the physical phenomenon, process the observed data and communicate with other nodes. Complex real-time networked control syste was also discussed in a paper by Tian and Levy (2008).

WSN protocol includes the application layer, transport layer, network layer, data link layer, physical layer, power management plane, mobility management plane and the task management plane (EETIMES, 2008). Figure 1 shows the network and application layer specification. ZigBee and Bluetooth are the two standard technologies used in WSN, both operate within the Industrial Scientific and Medical band of 2.4 GHz and provide license-free operations, huge spectrum allocation and worldwide compatibility. Power requirement for the devices is directly proportional to the frequency and bandwidth increase, and transmission distance is considerably shorter (Callaway, 2004; Qingshan *et al.*, 2004). Various communication algorithms were developed for wireless network such as randomised routing algorithm and nine heuristic transmission scheduling algorithms (Li, 2010). They showed that the performance of their algorithms for undirected network was significantly better than the pipelined breadth-first search tree algorithm by exploiting more transmission concurrency (Li, 2010; Heinzelman *et al.*, 2002; Abbasi and Younis, 2007).

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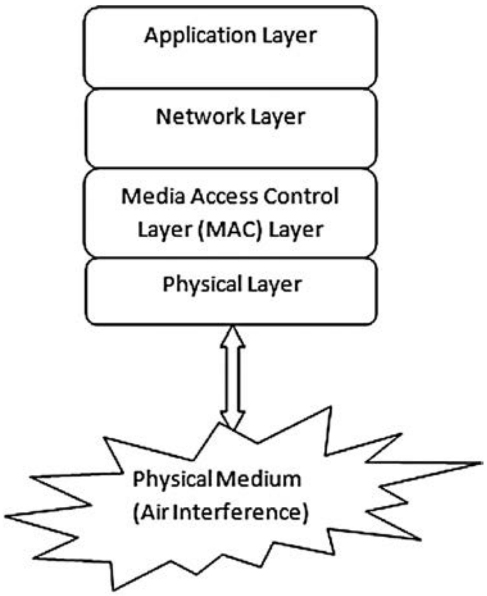
Figure 1 Network and application layer specification for WSN



Source: Wang (2011b)

As discussed in the paper by Lajara *et al.* (2011), battery replacement problem was eliminated using super capacitors recharged from a specifically designed solar power module, thus making the system completely autonomous and maintenance-free. The "wEcoValve mote" firmware was based on a synchronous protocol that allows bidirectional communication with a latency optimised for real-time work, with a synchronisation time between nodes of 4s, thus achieving a power consumption average of 2.9 mW (Lajara *et al.*, 2011).

WSN is dependant on the following equation: Sensing + CPU + Radio = Many possible applications, as shown in Figure 2. WSN has two types: structured and unstructured. Further, there are five types of WSN, as discussed by Yick *et al.* (2008) and shown in Figure 3:

1 terrestrial WSN;
2 underground WSN;
3 underwater WSN;
4 multi-media WSN; and
5 mobile WSN.

A reliable energy-efficient multi-level routing algorithm in WSN was proposed in the paper by Yu *et al.* (2011); that

Figure 2 Dependant of WSN

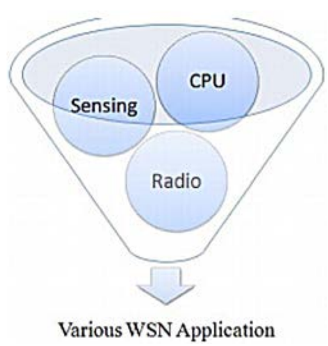
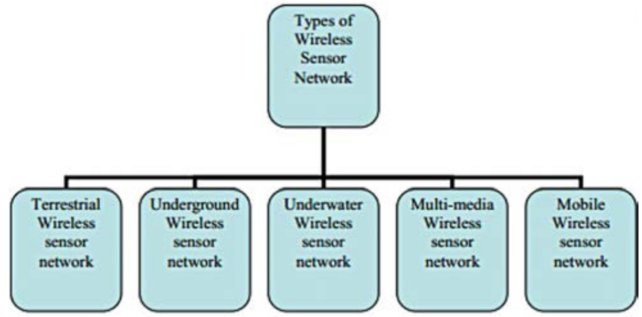


Figure 3 Types of WSN



Source: Yick *et al.* (2008)

algorithm considered the residual energy, number of the neighbours and centrality of each node in cluster formation, which was critical for well-balanced energy dissipation of the network. Simulation results showed that the proposed algorithm effectively prolongs the network lifetime and reduces the energy consumption (Yu *et al.*, 2011).

A collaborative variational/Monte Carlo scheme was proposed in the paper by Teng *et al.* (2011) to solve the multi-target tracking problem in WSNs. An energy-efficient service discovery protocol for heterogeneous WSNs that interact with the users in open and dynamic environments was proposed in a paper by Marin-Perianu *et al.* (2008). Wireless technology is being used in many fields including modelling for various day-to-day activities (Xu *et al.*, 2011).

The crucial component of the WSN is the vast sharing of data among sensors. As mentioned in a paper by Vidhyapriya and Vanathi (2009), the design and implementation of the two lossless data compression algorithms integrated with the shortest path routing technique to reduce the raw data size and to accomplish optimal trade-off between rate, energy and accuracy in a sensor network. The authors applied different types of data sets to validate their work and showed that it could reduce the energy consumption over the data compression schemes based on simulations.

Security of the WSN was described in the paper by Batina *et al.* (2006), where a low-cost public-key cryptography-based solution for security services such as key-distribution and authentication were required. To have a strong cryptography and less power, elliptical curve cryptography was proposed for implementation using custom hardware approach. The distributed sensor networks (DSNs) system generates huge amount of data, which is always a challenge for the detection system. A new method for optimal sensor allocation in a DSN with the objective of timely detection of the abnormalities in an underlying physical system is proposed in an article by Li and Jin (2010). However, a distributed trust management system was proposed for WSN to have secure communication (Geetha and Chandrasekaran, 2014). In a paper by Hwang *et al.* (2009), the authors discussed about a mathematical framework which includes the maximisation of network utility, maximisation of network lifetime and trade-off between network utility and network lifetime. Depending on the data flow rates, this framework would maximise the overall throughput of the network. The new mote has been developed and discussed regarding the better battery life, radio performances and networking algorithms (Kling *et al.*, 2005).WSN reliability was analysed using the fault tolerant method (Venkatesan *et al.*, 2013); the impulse noise effect on wireless network relay has been simulated and studied (Ghadimi *et al.*, 2012); even the WSN performance under the effect of collision and interference was studied (Onsy *et al.*, 2014). A better technique has been proposed for continuous monitoring of natural phenomenon and event-driven reporting (Azim *et al.*, 2014).

Politi *et al.* (2007) gave the details of the design and implementation of a hardware platform for WSN applications. The hardware platform was designed to address the constraints of size, cost and energy consumption imposed on WSN nodes, including the development of a power metering application based on the manufactured hardware devices which would measure and log the power consumption of different household or office appliances and transmit gathered information wirelessly to a base station which might also be utilised in testing and exploring various capabilities and functionalities of the hardware platform. Stability of the network infrastructure was ensured by sensor network routing protocols. Koliousis and Sventek (2007) have studied the behaviour of proactive and reactive routing schemes using TinyOS implementation, and their result showed that the reactive protocols were preferred over proactive protocol and vice versa at the time to repair and overhead space. In a paper by Barbaran *et al.* (2009), a case study of the usage of the Secure Middleware for Embedded Peer to Peer (SMEPP) for a programming standard has been discussed. The development of SMEPP applications was carried out through a neutral-language API which could be used in different languages such as Java or nesC. A real use of the middleware in an environmental monitoring application for nuclear power plants with WSN showing the suitability of the middleware to develop this kind of applications was presented in the paper by Barbaran *et al.* (2009).

A multi-objective immune co-evolutionary algorithm was proposed in a paper by Ding *et al.* (2011) for target coverage, as it was known that the target coverage is an important aspect in WSN. A tree-clustered data gathering protocol to improve upon the LEACH and TREEPSI methods was proposed. This protocol could help to reduce the power consumption, as it could preserve the advantages of the LEACH and TREEPSI methods (Yen *et al.*, 2011). Automated process for the wireless sensor and actor network application was discussed in the paper by Akkaya *et al.* (2010) that eliminates human intervention. The positioning of an actor can be determined by the sensor through the cluster head as representative.

Most of the WSN application built up using Mate, which is an application-specific virtual machine, helped to ease the programming task involved in building a WSN application. WSN deployment is mostly dependent on the hardware and software architecture. In a paper by Manickam (2005), Mate was used as a development tool, and further, the software had been evaluated for the hardware and software point of view. WSNs and their technologies, standards and applications were studied by Garcia-Hernandez *et al.* (2007), where the authors stressed on the realisation of sensor networks in which constraint such as fault tolerance, scalability, cost, hardware, topology change, environment and power consumption must have to be satisfied.

Sensor web infrastructure could be utilised for sharing, finding and accessing sensors and their data across different applications. The building block for a sensor web is the web service interfaces and data encoding. Broring *et al.* (2011) analysed the recent developments of the new generation of the sensor web enablement specification framework.

Information retrieval from sensor nodes using the query-based system is very much desirable. Authors of the paper have proposed the on-demand information retrieval approach for resolution of data queries according to the attributes and location of sensor nodes. Their results revealed that the scheme they proposed has reduced the power consumption and improved the balance of energy consumption among sensor nodes (Teng and Zhang, 2010).

Multitier WSN setup is the need of current time where network performance is required to be thoroughly evaluated (Yang *et al.*, 2013); also, an emerging technology such as OpenFlow is used to permit the flexible control of data by utilising the network switch programming via a standard interface (Yang *et al.*, 2014).

2. WSN application

Sensor nodes help in the environmental sensing and data processing, as they are equipped with a variety of sensors such as temperature, humidity and volatile compound detection for monitoring different environments (Callaway, 2004; Strutu and Popescu, 2011).

An approach of WSN and Code Division Multiple Access has been utilised for the resolution of real-time traditional water quality detection methods. In that, WSN monitored the water quality information of waters through the large amount of sensors. The optimisation of nodes was studied with respect to the reduction of energy consumption and effective acquisition of information through WSN (Wang *et al.*, 2010).

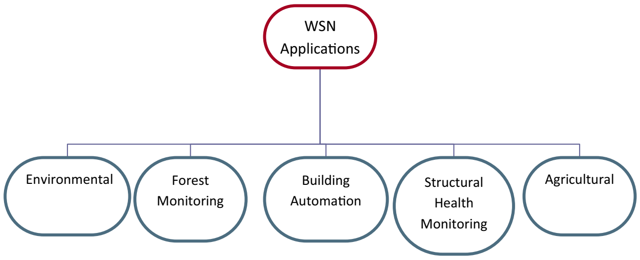
WSN technologies and standards are used in agri-food sectors and in several fields such as environmental monitoring, precision agriculture, cold chain control or traceability. ZigBee-based WSN and semi-passive and active radio frequency identification are very helpful in the agriculture and food industries with an economically viable replacement for wired networks (Ruiz-Garcia *et al.*, 2009).

In a paper by Bag and Bassiouni (2008), a cross-layer MAC protocol and routing protocol co-design were described for biomedical sensor networks. As described in the paper, the cross-layer interactions between the network and MAC layers help optimise the overall performance of the *in vivo* network. WSN was also used in anti-theft alarm system for photovoltaic panels (Bertoldo *et al.*, 2012), in application for monitoring elderly at home (Lu *et al.*, 2014) and in temperature acquisition system with an FPGA (Souissi and Ben-Ammar, 2014). WSN major application are shown in Figure 4 and details are given in the following sections.

2.1 Wireless sensor application in environmental field

Sensor network can be well-utilised in finding the environmental boundary for solving the problem of optimal coverage (Sohn, 2007). This could be done by deploying a suitable algorithm on the sensors (Wang, 2011a, 2011b). Real-world WSN application for monitoring and control is emerging; further, the benefits and costs of caching data for

Figure 4 Application of WSN



such an application are important. Several approaches to querying for and then caching data in a sensor field data server were discussed by Yates *et al.* (2007). Authors showed some application requirements such as delay in data quality, policies that may be involved in quality improvement and cost savings and also identified caching and lookup policies for which the sensor field query rate was bounded when servicing an arbitrary workload of user queries.

One of the WSN is COMMONSense Net, which aimed to provide environmental data from the fields to the farmers in developing countries. In a paper by Depienne (2007), TinyOS2 application for gathering of sensor data towards a sink in the COMMONSense in WSN has been discussed and further deployed as a first network in Bangalore as a wireless application for agriculture environment.

Automatic monitoring systems to prevent dew condensation in a greenhouse environment with the help of a WSN were discussed in a paper by Park and Park (2011). The building blocks of the systems were sensor nodes for collecting data, base nodes for processing collected data, relay nodes for driving devices for adjusting the environment inside greenhouse and an environment server for data storage and processing.

Ramesh (2009) described the use and evolution of WSN for landslide detection in the Idukki district of the southern states of Kerala, India. Geographical sensors were deployed for data retrieval and collection. WSN required the development of data collection and data aggregation for such application, including air pollution monitoring in the urban environment (Hejlová and Voženílek, 2013).

2.2 WSN application in other areas

2.2.1 Building automation

Wireless technologies have also helped in the building automation system (BAS) for solving the challenges like installation constraints, hardwiring installation. Wireless BAS has a great impact on facility performances, cost efficiency and new facility requirement, as mentioned in the paper by Wang (2011a, 2011b). Developing an energy usage model and solution in building automation with the help of a low-cost sensing module was discussed in a paper by Grindvoll *et al.* (2012). Building automation would be greatly benefited by the low-cost wireless sensor and control systems. With this the cost of system installation would be reduced and having more sensors deployed would help in the efficient building automation (Kintner-Meyer, 2005).

2.2.2 Forest management

A forest monitoring system solution using WSN based on ZigBee was discussed in the paper by Tao and Zhang (2009). It would help to improve the inefficiency of existing monitoring systems. In that paper, the hardware design of sensor node and network protocols were discussed which were found suitable for the forest monitoring system. The designed system would help in energy saving and maintains its reliability. However, it has been found that power management is an important aspect in forest management where a microbial fuel cell has come up as an alternative renewable source of energy for such applications (Yang *et al.*, 2012a, 2012b).

2.2.3 Structural health monitoring

Structural health monitoring (SHM) was discussed in a paper by Ruiz-Sandoval *et al.* (2008) as an emerging tool where smart sensors would be deployed to improve SHM. The first open hardware/software platform that was utilised in this study was Berkeley Mote; however, it could not be well-optimised for use in civil infrastructure applications. Sensor boards based on the Berkeley Mote platform had provided experimental verification in civil infrastructure applications. The SHM system using WSN was tested for detecting any change in the structural performance (ElSafty *et al.*, 2013). Further, automatic repeat request-based data transmission performance of IEEE 802.15.4 on the rotating object has been experimented (Yang *et al.*, 2012a, 2012b).

2.2.4 Agriculture

Papers by Aquino-Santos *et al.* (2011); Alberts *et al.* (2013) and Keshtgari and Deljoo (2012) discussed about the new WSN platform and its application in precision agriculture. Embedded operating system and its hierarchical and flat routing algorithms were discussed and tested in a small-scale network applied to a watermelon field. Their results showed that the modified LORA-CBF, a wireless location-based routing algorithm, functioned well with both flat and hierarchical algorithms and better with flat algorithms in the small-scale agriculture network.

A sensor for high-resolution mapping of soil pH at the field scale from USA was available, and in a paper by Schirrmann *et al.* (2011), the authors had evaluated that for the farming conditions in Germany. Authors compared the sensor reading with the data received by standard protocols of soil pH assessment.

2.2.5 Traffic monitoring

Ruiz-Garcia *et al.* (2009) reported WiFi and WiMAX-like technologies are widely penetrated into the traffic control and management application for its effectiveness and reliability. Well-designed wireless option is a must for different traffic control and management application. The South Carolina Department of Transportation traffic camera system was connected via WiFi or WiMAX network architecture. Network simulator NS-2 was used to access the throughput. This article provided the basic guidelines for the WiFi and WiMAX system in traffic system, of its performance and reliability. Average throughput of each camera received in different network topologies was accessed by using the network simulator NS-2 (Zhou *et al.*, 2011).

Manickam (2005) focussed on micro electro mechanical system. Pressure sensors integrated with the wireless ZigBee network for real-time bridge scour monitoring. The model was used to calculate the scour depth evolution and validation with real-time measured data. The results indicated that the system

Table I SWOT analysis of the WSN (WikiWealth)

Strength	Weakness	Opportunities	Threat
Technology	Cost	New era on R&D	Lack of popularisation
Size advantages	Customisation	Innovation	Availability issues
Feasible at hazardous location		New market	Government regulation
Uniqueness			

has potential applicability to monitor scour evolution in the field.

The conference and workshops on WSN indicated the scope of WSN in the emerging area of energy efficiency, security, underwater medical sensor networks, opportunistic spectrum access and data caching and storage in *ad hoc* and sensor network (Xing and Misic, 2010).

WSN for development (WSN4D) was discussed with its need for technology research and development. It would help to mitigate developmental problems and also facilitate research activities such as environmental monitoring, physics of complex systems and energy management (Zennaro *et al.*, 2008).

3. Discussion

WSN has been started with the aim to help the environment and people with its different applications. This could be monitoring surveillance and so on; technologically, WSN systems are coming with the improved models so that they can be very well-accommodated in the need of the hour. WSN does miracles in the places where human intervention could be dangerous and may lead to hazards such as remote sites for mines. Environmental fields are the main receptors of WSN and its technological development. WSN types such as terrestrial, underground, underwater, multimedia and mobile cover all the aspects of the environment. Underwater WSN can be very well-deployed in the water quality monitoring and measurement and likewise others too. Mobile wireless sensor could be utilised in any of the roaming activities. There are some other areas also where WSN has been used, like building automation, traffic control and surveillance, etc.

As discussed above, sensors are having a wide variety of applications in the field of environment; hence, many scientists and researchers are focusing to move further for solving the complex environmental problem using this tool.

Table I describes the SWOT analysis of the WSN (WikiWealth, 2014), where its strength lies in the technology, compact circuitry and that too most important to the situation where human intervention is not possible due to safety reasons. It has the uniqueness in its design, whereas the cost and further customisation are somewhat its weaknesses. WSN has got many opportunities, which include more innovation, open new market, new technology and new products. However, the major threat to WSN is less popularisation, non-availability and government regulation.

4. Conclusion

WSN conceptualised in 1998, it consists of sensor nodes with sensing data processing and wireless component. Application layer, transport layer, network layer, data link layer, physical layer, power management plane, mobility management plane and task management plane are included in the WSN protocol, whereas ZigBee and Bluetooth are used in WSN. Various types of WSN systems for different types of application have been given in the paper. WSN application was explored in environmental studies, building automation and surveillance system. Its application in the field of environment is very effective to tackle the upcoming environmental challenges. Wireless sensors are very beneficial for the environmental application, where the author tried to showcase the various usage of the WSN, especially in the environmental and other related fields.

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About the author

Poonam Prasad was born in India in 1982. She received her BTech degree in electronics and communication in 2005 and a postgraduate diploma in environmental law in 2014.Currently, she is Scientist and Head of Knowledge Resource Center at CSIR-National Environmental Engineering Research Institute, Nagpur, India. Her major area of work is in environmental systems and knowledge resource management and maintenance. She is also involved in the project related to expert system and framework design. Poonam Prasad can be contacted at: p_prasad@neeri.res.in