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Full Length Research Paper

A review on wireless sensor networks routing protocol: Challenge in energy perspective

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Wireless sensor networks (WSNs) technology consists of a number of sensor nodes that are dispersed in a geographically distributed area usually for monitoring purposes. The widespread applications of WSN have fueled the emergence and acceptance of this technology as a frontrunner. However, the success of the wireless sensor network applications highly depends on the reliable communication among the sensor nodes. One of the major problems in wireless sensor network environments is the limitation of the physical resource that is energy resources. The node energy is a critical constraint that needs addressing in order to achieve the demanding goals of wireless sensor network applications. High energy consumption in the sensor node occurs when data is disseminated to the other nodes in wireless sensor networks. Data delivery in specific time slot holds the key position for the successful completion of tasks assigned to sensor nodes and hence the application those sensors are serving. The wireless sensor network applications are in high demand nowadays. Time delay in packet delivery can save lives. The data in WSN hops from one node to another in order to reach the destination if the receiver node is not in a direct radio range of the sender. This paper provides a critical analysis on the impact of the previous methods on the reliability and energy efficiency for routing protocol in multi-hop wireless sensor networks. At the end of this paper, a characterized comparison has been forwarded on these methods based on the analysis outcome.

Key words: Wireless sensor networks, data-centric protocols, data dissemination, reliable communication, energy efficiency.

INTRODUCTION

A wireless sensor network (WSN) is a formation of a number of nodes (even hundred and thousands of them) that communicate with each other to perform sensing process and intern an application that relies on sensor readings. Normally each node is equipped with a battery to power it up, a main board with a chip and memory that acts as a CPU for the nodes (Gajbhiye and Mahajan, 2008; Giuseppe et al., 2009; Zhang, 2009). Each node has sensing capabilities to sense the environment information (temperature, earthquake etc.) and process the information to be sent through the radio links in a network to a destination node. Nodes can be thousands in number and each node is connected to each other to form a communication network. All the nodes are monitored and controlled by a base-station or sink node which is responsible to receive all information sensed by the nodes (Karl and Willig, 2007). In recent years, wireless sensor networks are used in real time applications such as environment monitoring, health monitoring and military where the data in this application is considered as critical (Junyoung et al., 2009; Zabin et al., 2008; Ben et al., 2009). Hence, reliable communication is crucial since real-time data must meet the deadline given for the data transmission (Junyoung et al., 2009; He et al., 2002; Martirosyan et al., 2008). To ensure the reliability in wireless sensor networks application, the power efficiency needs to be focused

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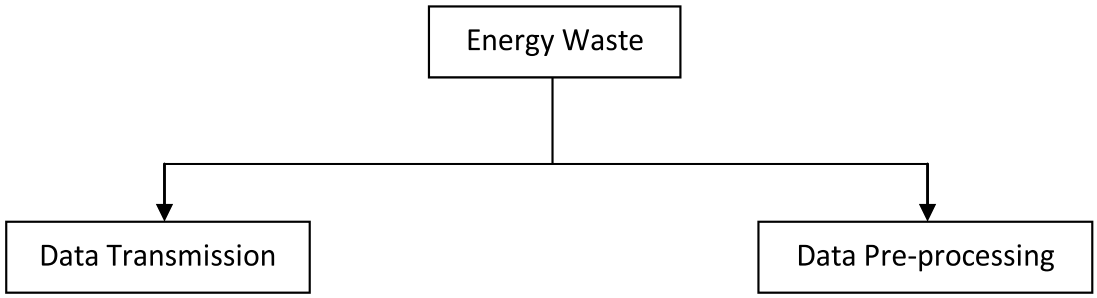

Figure 1. Energy waste in sensor nodes.

since sensor nodes have a limitation in power supply (Giuseppe et al., 2009). As the use of wireless sensor networks in applications is rapidly growing, the power efficiency in wireless sensor networks stays as the unsolved main factor and needs serious consideration in order to ensure the success of the technology. Therefore, power efficiency in wireless sensor networks is a critical part and in recent years, this part has been a focal point for researchers to improve the efficiency in power usage. As nodes use battery for powering up, it is a finite resource that ends a nodes operation as it dries out itself. It can affect the sensor lifetime since the sensor depends on the battery to power the sensor (Karl and Willig, 2007). As power is the main part in wireless sensor networks application, it is important to ensure the power efficiency in each node (Giuseppe et al., 2009). Hence, power consumption is critical in wireless sensor networks and the most important part in developing any application is ensuring the power usage more efficient. Sensing the information and processing already consumes high energy in sensor nodes, which yet to include the energy needed to transmit the information to other nodes (Giuseppe et al., 2009; Giuseppe et al., 2009).

According to Giuseppe et al. (2009), the cost of energy is expensive when the sensor nodes are in transmitting process compared to processing the data in sensor nodes. Energy wastage can be expanded into two categories which are data transmission and data pre-processing (Giuseppe et al., 2009). Figure 1 shows how the energy waste can be narrowed down into sub categories which have been main focus of previous studies. Data transmission is related with the sensor nodes transmitter where the sensor nodes use it to transmit a signal to the destination node. If the transmitter remains active even though there is no activity for transmission, more energy will be depleted since it generally consumes more energy than the sensor nodes processing element (Giuseppe et al., 2009). On the other hand, pre-processing element is where the sensor nodes are relatively executing the data itself inside the sensor nodes such as sensing the information, processing the information and extracting the received information. These activities also could mislead the energy if the processing element is not well managed where the same sensor node is required to do the sensing process. Energy has been a critical issue since the emergence of wireless sensor networks technology and it should be an important element when designing the routing protocol. Nevertheless, the communication reliability needs to be considered when taking energy perspective as a main element since reliability communication gives a significant impact for a success in wireless sensor networks especially in real-time environment (Junyoung et al., 2009; Akkaya and Mohamed, 2005a). Through reliable communication, the routing protocol with energy conservation has the ability to improve not only the sensor nodes neither prolonging the sensor nodes; it should also have the ability to ensure the transmission of critical packet in deadline delivery. Reliable communication can provide a guarantee for the data transmission from source to destination. Since multi-hop communication has been adapted for most of the energy efficiency routing algorithm, the multi-hop mechanism has forwarded a problem for reliable communication, as multi-hop process is time consuming where it takes one node to the others before reaching the destination (Shao-Shan et al., 2007; Karl and Willig, 2007).

In reliable communication, this constraint does not cause a serious problem since the data is successfully delivered without any error in destination node (Junyoung et al., 2009). Deadline delivery requires a timeline for delivering the data to the destination, thus a delay would occur due to the multi-hop mechanism constraint such as packet loss in intermediate nodes where a retransmission is acquired. Figure 2 shows the two important elements in reliable communication for wireless sensor networks, which are real- time environment and non real-time environment, and each element has its own characteristics of requirements.

Wireless sensor networks scenario

Sensor nodes act as a main component in wireless

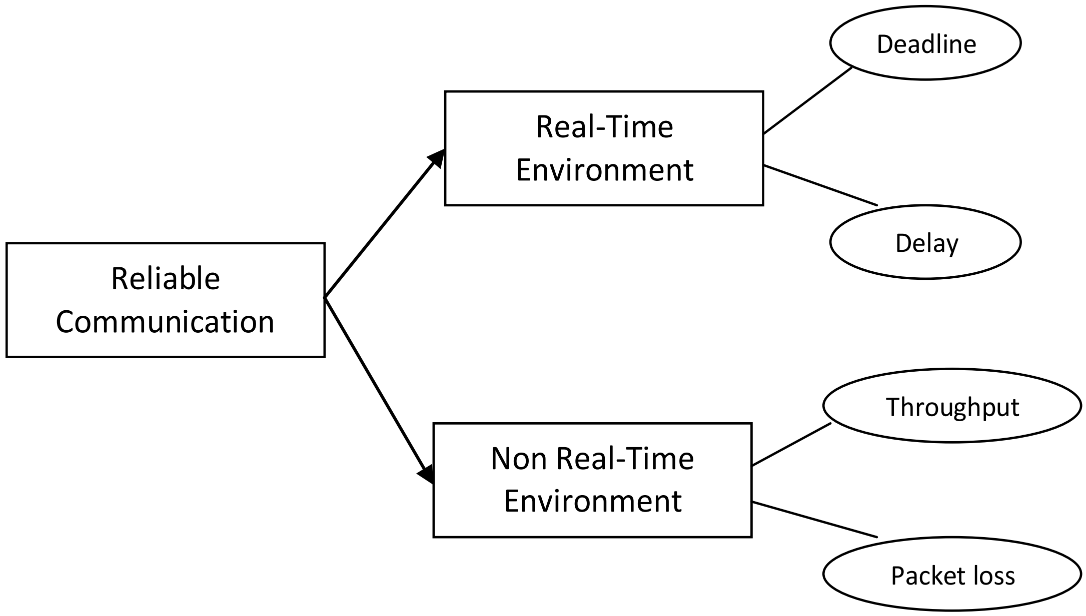

Figure 2. Reliable communication elements.

sensor networks for gaining the information using sensing application (Boukerche, 2009; Karl and Willig, 2007). Wireless sensor networks are basically a technology adopted from the sensor network application which is differentiated by the communication medium and sensor hardware capabilities. In wireless sensor networks, the sensor is a number of collective nodes that scatter around selected places and form a network. The nodes are considered as small physical devices compared to the devices used in computer networks. Furthermore, sensor nodes depend only on the battery to power the nodes up rather than electric-based which can be used in traditional networks. Hence, wireless sensor networks application has a huge impact especially in the power consumption management (Yan, 2006; Giuseppe et al., 2009). As this scenario poses more challenges in the wireless sensor networks environment, the previous researches have made a significant enhancement for improving the application.

Basic principles in wireless sensor networks

Every new technology has greater challenges than its benefits in infancy. As wireless sensor networks have emerged recently, challenges in this technology are unique due to its different behavior (Wang and Liu, 2010). In ad hoc networks, there are several architectural constrains that need to be addressed. As these hurdles are well anticipated in ad hoc networks, WSN inherits some of these design level hurdles. All these challenges have one root effect on the WSN node; power loss. According to Karl and Willig (2007), some of the basic requirements for wireless sensor networks are as follows:

Quality of service (QoS)

As it is synonym to network technology; QoS is a compulsory requirement to any network technology. In wireless sensor networks, QoS metric value is needed since most of the wireless sensor networks applications are of real time fashion.

Lifetime

As mentioned earlier, sensor nodes depend on batteries to power them up. Replacing the batteries when they run out of energy is not practical and unsuitable since the nodes are scattered among the location. This challenge makes wireless sensor networks research focuses more to invent any solution that relates with energy part.

Scalability

The network must have the ability to scale all the nodes whether the node is less or more.

These requirements will give significant impact on the efficiency in applications that use wireless sensor networks technology (Karl and Willig, 2007). Previous studies focused on these requirements as a core topic. In real-time applications, Junyoung et al. (2009) proposed a protocol which guaranteed the packet arrival to the destination nodes. Another approach by Sumathi and Srinivasan (2009), in which they proposed a protocol that guarantees the QoS upon delivery on critical packet only with low delivery latency. Most of the previous works have different approaches on which problem they want to overcome and solve. Instead of using different approaches, most of the previous works have one main purpose; how to ensure the lifetime of network, since the nodes have a limitation of power capabilities. A brief explanation on this will be discussed later in this study.

Wireless sensor networks vs wireless ad hoc networks (MANETs)

As wireless sensor networks differ from the mobile ad hoc wireless network, it is important to recognize how and what important characteristics that differentiate them. According to Hischke and Walke (2003), mobile ad hoc network is a network which consists of nodes where each node has the capability to communicate with each other without relying on specific devices such as routers for wired network or access point for wireless network. MANETs is a technology where the principal and concept are similar with wireless sensor networks which are to send information among the network participants which are the nodes. The notion of mobile itself shows the capabilities of the computers moving around the area surrounded by the coverage (Karl and Willig, 2007). MANETs and wireless sensor networks have similar problems in general such as the coverage area, QoS guarantees, availability and scalability (Al Turki and Mehmood, 2008; Karl and Willig, 2007; Sumathi and Srinivasan, 2009). However, there are specific needs which separate these technologies as noted by Karl and Willig (2007) and Boukerche (2009), of which some of them are as follows:

Applications and equipment

Applications in MANETs are slightly different compared to ‘wireless sensor networks’. For example, MANETs can be used for voice and video communication but wireless sensor network is an application based on nodes sensing process. From the equipment point of view, MANETs is equipped with powerful devices such as laptops, PDAs which have large battery capacity comparing to wireless sensor networks equipment which depends on sensor nodes that are equipped by low battery capacity.

Scalability

In wireless sensor networks, it can be up to thousands of nodes in the networks which need to be more scalable. As mentioned byKarl and Willig (2007), location is a high priority than specific node identifiers. Thus, appointed nodes with a unique identifier can produce low productivity and low runtime which can cause an overhead. Hence, the best solution is to provide the protocol without identifier method, whereas MANETs can implement this method to identify the equipments.

Energy

Both MANETs and wireless sensor networks have problem in energy conservation, but it is more critical in wireless sensor networks since nodes have lower power capacity than equipments in MANETs. Batteries equipped with sensor nodes have limited lifetime compared to PDAs battery or laptops battery. These differences show that previous works on wireless sensor networks focused within these characteristics but through different approaches. Later in this chapter, a previous work will be deliberately discussed to show how it relatively focused on these characteristics.

Network architecture and environment for wireless sensor networks

In designing wireless sensor networks, individual sensor node needs to be somehow connected with each other to achieve the main purpose; sending sensed information from sensor nodes to the base (Karl and Willig, 2007). Thus, the architecture for network design is similar with MANETs but only different on the approaches based on the characteristics discussed previously. Basically, wireless sensor networks application must consider the energy restriction in sensor nodes (Giuseppe et al., 2009). Furthermore, wireless sensor networks are designed for applications based on real time computing (Mahapatra et al., 2006; Junyoung et al., 2009; Park et al., 2006; Martirosyan et al., 2008; Akkaya and Mohamed, 2005b). Thus, the design of wireless sensor networks application must consider these requirements. Relatively, there is a different view on the designing requirements for wireless sensor networks from the previous studies where the energy had been focused; since this issue is very critical in designing the wireless sensor networks application (Giuseppe et al., 2009; Giuseppe et al., 2009; Akkaya and Mohamed, 2005a). In wireless sensor networks environment, there are two main entities which can be considered important when designing the wireless sensor networks application; sources and sinks (Karl and Willig, 2007). A source is an entity which is responsible to send information through the network which is the sensor nodes. As for sink, it is an entity that requires the information sensed by sending a request to the sources (Karl and Willig, 2007). A sink

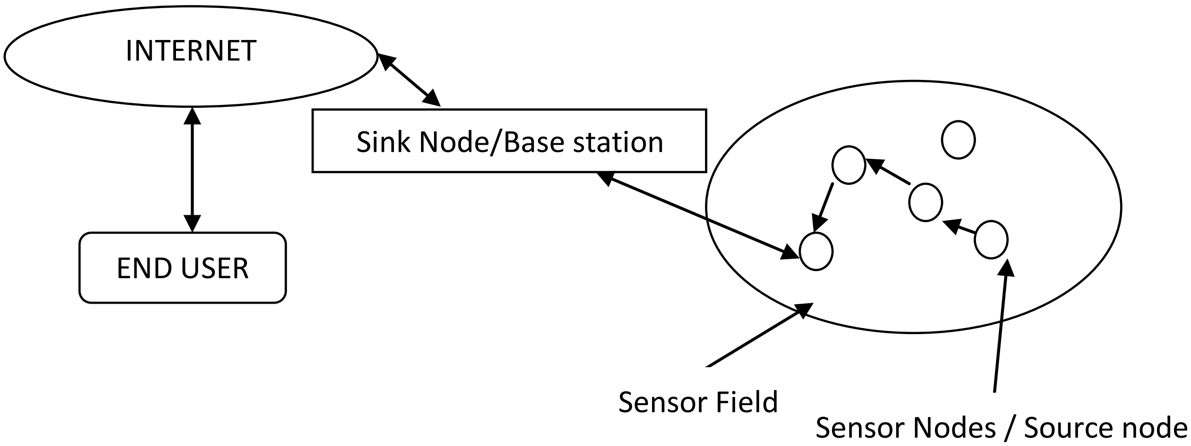

Figure 3. Wireless sensor networks model and architecture.

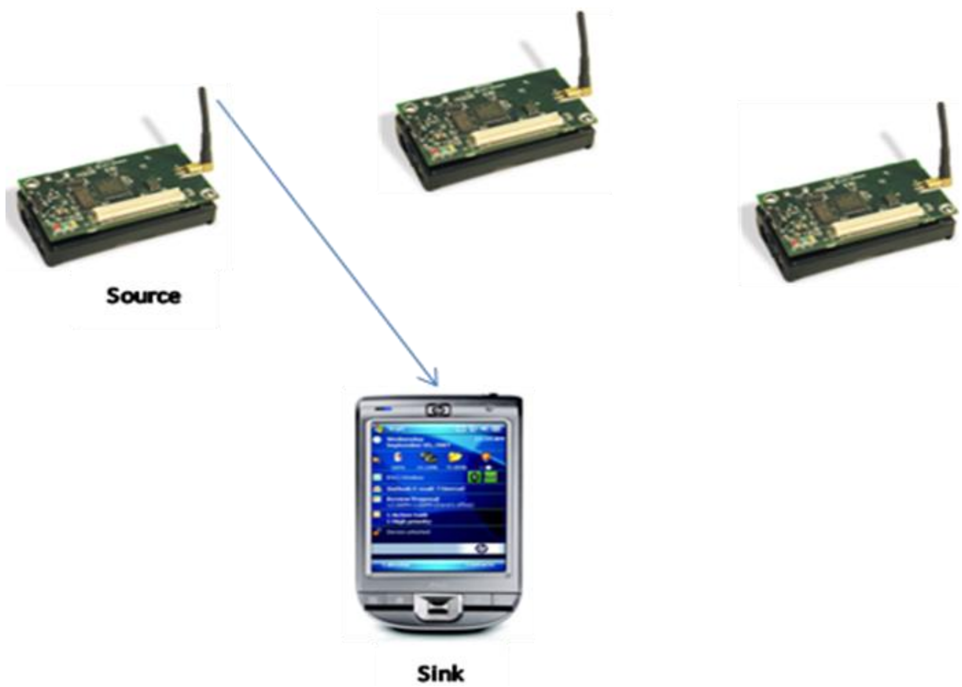

Figure 4. Single-hop communication.

also could be a sensor node itself depending on the application requirements. Basically, the sink acts as a base station which handles all the information sent by the sensor nodes. For this scenario, the sink can be a PDAs, servers (computers) and not possible as a gateway to the internet where it is a less energy constraint (Younis et al., 2002). Thus, it is important to deliberately discuss how the communication between the two entities takes place.

In wireless ad hoc networks, the communication between each device can be done in a single-hop or multi-hop communication (Karl and Willig, 2007). Hence, wireless sensor networks adopt these communication scenarios to execute communication between the sink and sources. Figure 3 shows that a basic model for wireless sensor network architecture which consists of sink node, sensor nodes and end user equipment.

Single-hop and multi-hop communication

In wireless sensor networks, a single-hop communication can be considered as not always possible since the

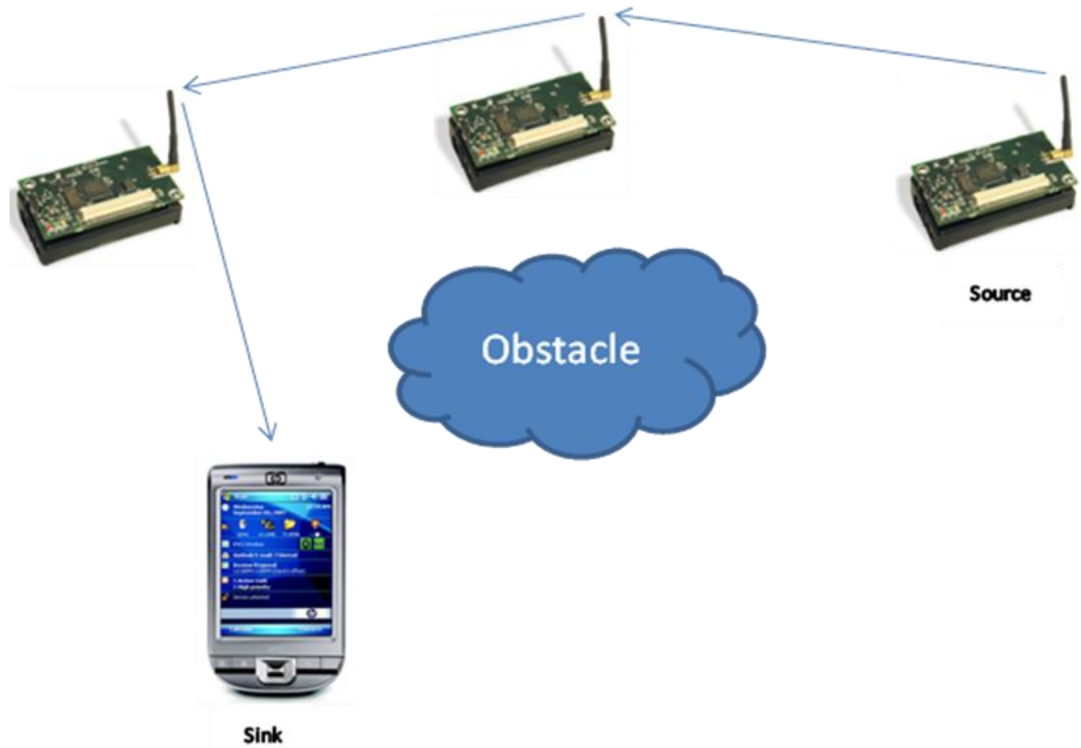

Figure 5. Multi-hop communication with obstacle between source and sink.

distribution of nodes is scattered among the selected area (Karl and Willig, 2007). Single-hop communication is a direct communication between the transceiver (signal device) of source and sink. Transceiver is limited by the restriction of distance by the covering signal, thus some situations restrict the implementation of single-hop communication when the distance has obstacles between the source and sink (Karl and Willig, 2007). Figure 4 shows simple types of single-hop wireless sensor networks. Multi-hop communication can overcome the problems suffered by single hop communication (Karl and Willig, 2007). In multi-hop, relay technique is used which transmit data packets from the source to the sink (Karl and Willig, 2007). Relay technique is a method that uses nodes as a temporary medium to transmit the packet from one node to the others. The nodes can be called as intermediate nodes since the nodes sit between the sources (original) and sink (destination). Figure 5 shows an example of multi hopping communication where there is an obstacle between the source and the sink. Although multi-hop can improve communication between source and sinks in wireless sensor networks, the guarantee of multi-hop routes existence is not permanent nor that the route is particular short (Karl and Willig, 2007). While multi-hop can overcome the problem in a large communication area, it does have a capability to improve energy efficiency in sensor nodes since multi-hop techniques require transmission of neighboring nodes which are literally close with each other thus decreasing the transmitter functionality (Giuseppe et al., 2009).

As mentioned earlier, energy conservation is a common issue in wireless sensor networks environment where the sensor nodes energy needs to be preserved.

Wireless sensor network performance optimization

Every network application demands high performance to ensure the network to be highly efficient among the users. In designing network application, there are some characteristics needed to be considered for ensuring the network performance to be highly efficient (Karl and Willig, 2007; Boukerche, 2009; Akkaya and Mohamed, 2005a; Giuseppe et al., 2009). For wireless sensor networks application, the characteristics for network performance which are derived from the traditional network need to be considered since they share the main goal; sending the packet from the source to the destination through the network. Instead of having the same network performance criteria such as bandwidth, availability, low packet loss and throughput, there is other criterion or goal which needs to be highlighted for ensuring the performance in wireless sensor networks application. According to Karl and Willig (2007), quality of service (QoS), energy efficiency, scalability and robustness are the criteria that measure the performance on wireless sensor networks application in terms of network performance. These criteria have made a significant impact on previous researches due to its importance in wireless sensor networks application. According to Karl and Willig (2007), wireless sensor network is one of a type ad hoc network which depends on limited power source nodes, limitation on nodes mobility and large scale network topology. As mentioned by Karl and Willig (2007), the main difference between ad hoc network and wireless sensor networks is by the application that they applied for. As wireless sensor networks application is to monitoring and sensing application, it should be more real-time base since the packet loss from transmission needs to be minimal (Akkaya and Mohamed, 2005b; Fapojuwo and Cano-Tinoco, 2009). Hence, reliable communication is a requirement for wireless sensor networks application to maximize the network performance for wireless sensor networks. Real-time environment has been considered critical since the emergence of the wireless sensor networks technology. Furthermore, several studies have been forwarded to provide the reliable communication in real-time environment for wireless sensor networks.

Reliable communication in wireless sensor networks still depends on the requirements of real-time environment which is deadline elements. A brief literature on these studies will be carried out later in this chapter to explain the mechanism for providing reliable communication in wireless sensor networks with real-time environment. Energy efficiency problem in wireless sensor networks has grown rapidly nowadays. The current technology in small devices has dramatically grown, which produce a small sized, low power and low cost sensor devices (Anastasi et al., 2009; Chamam and Pierre, 2009; Junyoung et al., 2009; Zabin et al., 2008). As the manufacturers have integrated a number of functions which are sensing, data processing and wireless communication capabilities into small equipment, the challenge to prolong the equipment based on the application in wireless sensor networks has become more critical. As the device has a capability of 4 MHZ CPU, with a little memory space and a 4 kbps wireless communication rate, it has been proven that energy conservation in the device is extremely important since the small device is powered up by a battery (Giuseppe et al., 2009; Anastasi et al., 2004). Since the energy consumption is the main limitation in sensor nodes for wireless sensor networks, the most important goal for designing wireless sensor networks application is to have a protocol and processing with an efficient power management without compromising the ability of network performance (Anastasi et al., 2009; Heinzelman et al., 2000; Karl and Willig, 2007; Akkaya and Mohamed, 2005b). As mentioned by Karl and Willig (2007), numerous solutions can be innovated to avoid any wasted energy consumption such as minimizing the total of energy spent in the network, minimizing the data transmission, combining the energy efficiency with fault tolerance approach without spending much energy in it and balancing the energy consumption between every sensor nodes. The previous researches in most wireless sensor networks area mainly focus on one problem; how to overcome the limitation of energy in wireless sensor networks without compromising the ability of the network performance itself.

Having a better energy efficiency management in wireless sensor networks application can prolong the sensor lifetime which ensures the success of wireless sensor networks application.

Wireless sensor networks data communication

In conventional network communication requirements, layering concept is the basic structure to illustrate how the network goes through the system itself (Kurose and Ross, 2003). There are application layer, transport layer, network layer, data link layer (with MAC layer as sub layer) and physical layer. Each layer has their own responsibility for transmitting the data successfully. As similar with traditional network layer, wireless sensor networks layer has its own responsibility to ensure successful transmission over wireless communication (Karl and Willig, 2007). In wireless sensor networks, packet or data transmission is linked with data communication area which relates to certain layer; the link layer or MAC layer, network layer (routing protocols) and transport layer (transport protocol) (Karl and Willig, 2007). As this element is a key for successful transmission process for wireless sensor networks, these layers will contribute to successful wireless sensor networks application with better power management and reliable communication. A basic introduction on these layers from Karl and Willig (2007) are as follows:

Data link layer/MAC layer: MAC protocol is to determine the time for nodes for the time which the nodes needs to access the medium for transmitting data, controlling or managing the packet whether to one node (unicast) or a set of node (multicast, broadcast). As for the data link layer, there are two most important responsibilities which are the error control and flow control (Karl and Willig, 2007). Error control is to detect any error packet transmission from the sender to the receiver which it needs to correct it, and flow control is responsible to balance the speed for transmission between the sender and the receiver for protecting the data being error.

Transport layer: In traditional network such as the Internet, TCP and UDP are the most important protocols for transport protocol. These protocols are commonly used for any network application design. Wireless sensor networks differ from these elements where wireless sensor networks transport layer concerns about the reliable communication service for the application layer.

Network layer: Routing protocol is a part of network layer which is responsible for transmitting the packet through the series of nodes. According to Lu et al. (2002), this is called as unicast communication. As this part is a main area for the research, this chapter will later explain briefly on the routing protocol area. It includes the two major elements to be achieved in this research, which are the energy efficiency in wireless sensor networks routing mechanism and reliable communication for real-time environment. These elements will be discussed on how the previous work concentrated on the routing protocol area.

ENERGY CONSERVING METHOD FOR NETWORK OPTIMIZATION IN WIRELESS SENSOR NETWORKS

Computer networks requires high optimizations in network performance such as high throughput, low packet loss and high bandwidth capacity to ensure the computer network application to be more reliable (Junyoung et al., 2009; Park et al., 2006). Routing procedure is to get a route for data transmission from the source to the destination based on the route selected by the routing algorithm. In reality, these processes are done by routing protocol which has been designed based on the routing algorithm. Routing protocol is responsible to find a suitable route for data transmission in network environment application which consists of a number of nodes or computers (Akkaya and Mohamed, 2005a). An efficient routing protocol in network application is measured by the success of the routing protocol to handle the application requirements such as QoS aware, shortest path and energy aware, thus, the routing protocol can be accepted by any applications in computer network environment (Mahapatra et al., 2006; Ming-Jer, 2009; Wang and Liu, 2010). A number of routing protocols have been proposed to solve the problem in data route process. Most of them literally gave a significant result to select a route for transmission, especially the route with shortest path distance since it generally improved the network performance especially in speed and network latency (Kurose and Ross, 2003; Boukerche, 2009; Lotf and Ghazani, 2010). Hence, the algorithm to solve the route selection is an important factor to determine the protocol as efficient in specific network requirements. As routing protocol plays an important role on determining for route path in network communication, a successful wireless sensor network application depends on the highly efficient routing algorithm design for routing protocol in wireless sensor network (Karl and Willig, 2007; Giuseppe et al., 2009). As mentioned earlier, the primary factor which differentiates between wireless ad hoc network and wireless sensor network is on the node device capabilities especially in energy perspective. As sensor nodes have a restriction on power capabilities and bandwidth resources, these constraints contribute challenges for designing and managing wireless sensor networks application.

In recent years, these challenges, especially in energy conservation have been focused in wireless sensor networks technology (Akkaya and Mohamed, 2005a; Giuseppe et al., 2009; Karl and Willig, 2007). In general, physical layer and link layer are the commonly related issues with the sensor device problem where the research has been focusing on the radio communication capabilities, signaling efficiency, low duty cycling and MAC protocols (Giuseppe et al., 2009; Karl and Willig, 2007). The research is to focus on network layer aspect which is to find a method for providing route selection with less energy spending by the nodes. In addition of that, the research is to design a method which provides reliable communication in data delivery for real-time environment. According to Karl and Willig (2007), challenges in routing in sensor networks are very critical based on the different characteristics between wireless ad hoc network which have been mentioned previously. As ad hoc network protocol uses global addressing scheme for identifying the devices, the protocol for wireless sensor networks is restricted for executing the same procedure which results in that IP-based protocol cannot be used in sensor networks (Zabin et al., 2008; Intanagonwiwat et al., 2003). There are numbers of challenges for designing the routing protocol for wireless sensor networks which were addressed by Karl and Willig (2007):

Sensed data flow management from multiple source to a designated sink in sensor network application.

Data redundancy

Generated data from multiple sensor nodes can be the same as other sensors thus needs to be avoided for improving energy and bandwidth capabilities.

Sensor nodes device capabilities management

Processing power and memory capacity.

Due to these challenges, most previous works and research for routing protocol in wireless sensor network focused on these problems. Among all these protocols, it can be classified as data centric, hierarchical and location-based (Akkaya and Mohamed, 2005a; Boukerche, 2009). In designing the routing protocol for wireless sensor networks, energy perspective has been considered as one of the major contributions in successful routing protocol. As proven by Anastasi et al. (2004) and Anastasi et al. (2009), energy is considered high consuming in sensor nodes when the data transmission is activated compared to data processing by the sensor nodes. Hence, energy saving approach can be categorized into two different parts which are in network system (energy management in single node, network protocol) and sensing process. Basically, energy can be reduced by focusing on sensor nodes processing function. Energy saving itself is highly depending on how the sensor nodes operate, thus most of the studies on energy efficiency focused on the sensor node itself especially on the physical layer and MAC layer (Ye et al., 2004; Demirkol et al., 2006; Sung-Chan, 2007). Studies by Giuseppe et al. (2009) have forwarded three different approaches to conserve the energy in sensor nodes which are duty cycling, data driven and mobility. Duty cycling approach is to control the power management between the sensor nodes where sensor nodes can be put on sleep mode when not operating. Data driven approach mainly focuses to reduce a number of data being sent to sink node which means to reduce the data redundancy. This approach is to use data aggregation techniques which intend to combine the data from different sensor nodes by using some techniques for aggregation (Heinzelman et al., 2000). Energy consumption is high when sensor nodes move around more frequently. Mobility techniques are to prevent such problem where it depends on the network infrastructure and environment (Yu et al., 2001).

Several studies have focused energy perspective in routing protocol which intends to reduce energy usage in route path establishment. In routing protocol, energy consumption is depending on how frequent the sensor nodes are being used to be a path to destination (Jones et al., 2001). The routing algorithm design is a critical part for ensuring the low energy consumption between the sensor nodes. Clustering technique is considered as an energy saving approach since the nodes are clustered between them and routing algorithm can set the path using the clustering method (Akkaya and Mohamed, 2005b; Younis et al., 2002). Energy is one of the critical issues in wireless sensor networks performance. Nevertheless, energy perspective may produce inefficiency on the reliability and bandwidth performance on packet transmitting (Park et al., 2006; Junyoung et al., 2009). Most energy saving methods focus on how to limit the process in each sensor nodes and this can lead to an inefficient transmission if related with real time application. In recent years, real time application in wireless sensor networks has become more critical since it requires high reliability to ensure high rate data transmission (Lu et al., 2002; He et al., 2002). Several studies have been forwarded to propose new methods for producing reliable communication in real time environment. In real time application, a requirement on bandwidth and minimum delay is the most critical point. Thus, designing the routing mechanism needs to take these points to ensure that the real time requirements are fulfilled. In the subsequent study, this classification will be described briefly with all the previous works related with the classification. The elaboration will focus on the protocol which tackles the energy aspect in selecting route path for transmission process.

As reliable, communication measurement is one of the research points; a brief literature on previous researches for reliable communication in real-time routing protocol for wireless sensor network will be carried out as well. To begin the explanation on these classifications, a short literature review on duty cycling for wireless sensor networks is included to emphasize the efficiency of duty cycling method in preserving the energy in sensor nodes.

LITERATURE IN ENERGY CONSERVING METHOD

Here, the previous research for energy conserving method in routing protocol is discussed briefly. The routing mechanism for ensuring reliable communication in wireless sensor networks that preserves the energy resource is also described.

Duty cycling in wireless sensor network

Medium access control (MAC) is responsible to stabilize the access of communication medium by the number of nodes which consider the performance such as delay, throughput and fairness (Karl and Willig, 2007). According to Karl and Willig (2007) and Ye et al. (2004), the research on MAC protocol has been widely exposed more than 30 years which contributes a largely number of literature currently. Since the emergence of wireless sensor networks technology, energy perspective has become a top priority in MAC protocol research for wireless sensor networks (Yan, 2006; Sung-Chan, 2007). Most researches on MAC protocol are considered the energy perspective regardless the traditional performance metric such as delay, throughput and fairness (Yan, 2006; Sung-Chan, 2007; Ye et al., 2004). In MAC protocol, energy consumption performance will evaluate the protocol significance if it can improve the energy consumption perspective. Duty cycling and wakeup concepts are methods which proved that energy waste can be reduced in transmitting packet through sensor nodes (Anastasi et al., 2009; Giuseppe et al., 2009). Transceiver in sensor nodes plays an important role to transmit data among the sensor nodes. As radio transceiver is controlled by the MAC protocol, duty cycling is one of the methods to reduce the use of radio transceiver since transceiver consumes the same energy quantity as the processing data in sensor nodes (Giuseppe et al., 2009). Figure 6 illustrates how the listen sleep concept is executed in time slotted techniques.

A study by Ye et al. (2004) has mentioned that energy wastage can occur with several major sources which are:

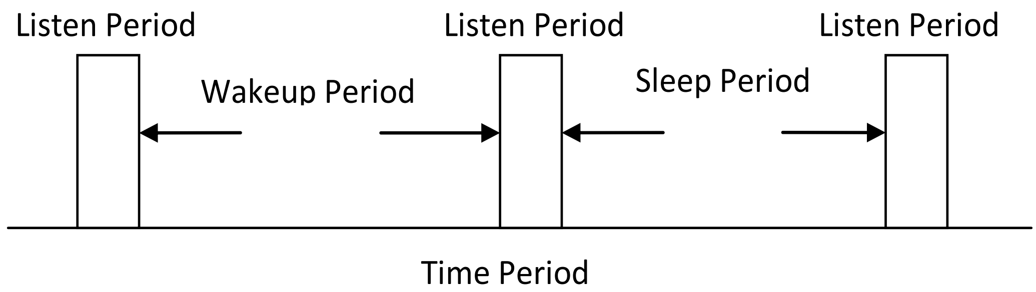

Figure 6. Periodic wakeup scheme.

Idle listening

Problem occurs when radio transceiver is turned on even though there is no data transmission in place.

Overhearing

Sensor nodes receive the packet and process it which does not belong to the nodes.

Overemitting

It occurs when sensor nodes are transmitting the packet but the receiver is not ready yet (sleep mode).

Collision

Simultaneous transmissions among the sensor nodes towards a receiver.

Probability sensor MAC (PS-MAC) by Sung-Chan (2007) was proposed to overcome idle listening problems with duty cycle technique. The protocol used S-MAC protocol as the principal protocol which was meant by an enhancement protocol. A new method has been included in the S-MAC which is a time slotted technique. Further explanation on S-MAC will be derived later. The time slotted technique is intended for sleep and listening period. To execute the listen-sleep in each time slotted, each sensor node will generate a pre-wakeup probability and seed number using pseudo random number generator method. PS-MAC has capabilities which each nodes transmitter and receiver does not use a periodic method scheduled as other methods do. This approach can cause an overemission when transmitting packet to nodes since the sender nodes do not have any information about their neighboring listen-sleep schedule. PS-MAC uses an exchanging method between neighboring nodes for exchanging their pre-wakeup probabilities and seed number. With this function, each node will have information about the sleep listen schedule of their neighbors. With the functionality of time slotted in PS-MAC, energy consumption can be reduced since the time to transmit is based on the time period in listen state. The transmitter will be put on sleep mode when sleep state is reached. According to a study by Giuseppe et al. (2009), energy consumption can be categorized into two different parts which are radio subsystem and sensing or processing component. They mentioned that energy is considered as high consuming when radio transmitter is in process rather than processing components. To overcome this problem, a protocol Adaptive staggered sleep protocol (ASLEEP) has been proposed with approach techniques which are basically to put the radio transmitter into sleep state during the idle state. This approach can be identified as duty cycling since it enables the transmitter regressing into sleep listen mode (Giuseppe et al., 2009). Basically, ASLEEP was designed on top of the MAC layer which means that ASLEEP does not rely on specific MAC protocol to transmit the packet. Even though ASLEEP is not exactly a MAC protocol, the approach being used to tackle the energy problem is similar with the problem that MAC problem encounters.

ASLEEP uses duty cycling concept, which is adopted from most of MAC protocol approaches for wireless sensor networks. Thus, the main advantage of ASLEEP protocol is that the protocol is not tied up with any particular MAC protocols , and which the protocol is flexible to be used in any sensor platforms. ASLEEP has two main core components that contribute the energy efficiency in sensor nodes which are the sleep prediction algorithm and sleep coordination algorithm (G. Anastasi et al., 2009). ASLEEP uses a concept of routing tree for organizing the sensor nodes where they root from sink node. All source nodes can be a parent node or child node and since the protocol has assumed that the topology is static, the routing tree should be stabilized when it is first calculated. In sleep prediction algorithm, the main part is the talk interval prediction where each node is to determine the time of active interval and silence interval which sensor nodes will turn their radio transmitter off for energy saving purposes. Figure 7

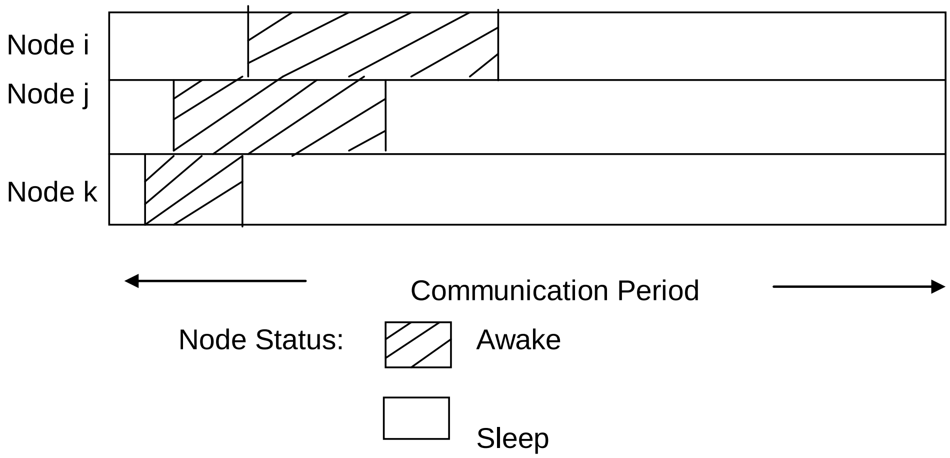

Figure 7. Talk interval between three different nodes.

shows a time period of three nodes which shows the time for active and sleep mode for each nodes. As shown in Figure 7, the talk interval between nodes i, j and k is determined by itself and the parent node will estimate their talk interval period to share among its children. According to Figure 7, node i is a parent node to nodes j and k and node j is a parent node to node k. Once the children nodes notice about their parent node talk interval, the children node will estimate their active period between the parent's active interval times. In sleep coordination algorithm, the important part in this segment is the direct and reverse beacons sent by the parent node to its child nodes and reverse. Basically, the procedure is to broadcast the sleep period of each sensor node among the network. Basically, beacon message is to alert the child nodes periodically to inform them that the parent node is still in active period. Thus, child node and the parent node will communicate between the active intervals. Another MAC protocol that uses duty cycling approach is S-MAC which aims to reduce the energy consumption waste based on the source (Ye et al., 2004). The S-MAC is designed based on the adaptation of periodic sleep and listen where the nodes are set to sleep in given time and wake up after a while to listen up to any communication between the nodes. The scheme enables the nodes to put their radios off when in sleep mode and automatically awake based on the timer set in the nodes.

Sleep and wakeup period is defined in one time frame length where in wakeup mode there is a listening state where nodes try to listen to any incoming communication from other nodes. It is called duty cycle. Duty cycle is a time interval where the nodes listen to any incoming communication. S-MAC synchronizes the sleep and listen schedule between immediate neighboring nodes where they share their sleep and listen schedule so synchronized nodes can be put into sleep or listen mode at the same time period.

Energy efficient routing mechanism in wireless sensor networks

Energy perspective in routing protocol is viewed on designing the routing protocol more efficient in terms of reliability in data transmission (Anastasi et al., 2009). Previous works proposed a number of methods to decrease the energy consumption in terms of route selection. As mentioned earlier, routing protocol in wireless sensor networks can be divided into three different categories which are: data centric, hierarchical and location based. This paper focuses on energy effect on static nodes, thus, it is sufficient to elaborate on the previous work for data centric and hierarchy since most of the routing protocols for data centric and hierarchical are limited to the static node environment (Akkaya and Mohamed, 2005a; Karl and Willig, 2007; Boukerche, 2009). Several studies have been made on each category to prevent any energy waste in sensor nodes. According to Akkaya and Mohamed (2005a) and Zabin et al. (2008), there are two important issues needed to be taken into account when designing routing protocol for wireless sensor networks which are maintaining each stage on the level of power consumption and different fault tolerance types to achieve. Since the power consumption is not only consumed when processing or sensing data, receiving or transmitting data from or to neighboring nodes is considered high (Giuseppe et al., 2009). Thus, designing the routing protocol with energy conservation aims to decrease the frequently used sensor nodes as a route path for sending the packet to receiver. These studies will be elaborated based on their categories and how well the protocol methods manage the power conservation.

Data centric routing protocols

Data centric routing can be categorized as a query based

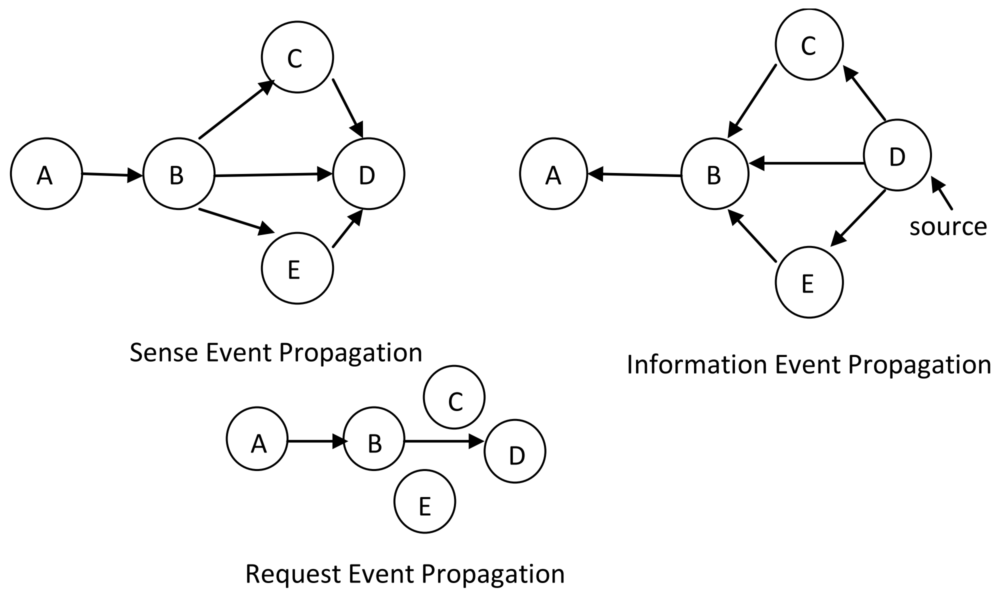

Figure 8. Propagation phase in REEP.

routing protocol which relies on the query given by the sink (Akkaya and Mohamed, 2005a; Boukerche, 2009). In computer network environment, the identification of each participant is important since it is one of the global identifiers to enable communication among them (Akkaya and Mohamed, 2005a). Application in sensor network does not have this capability since the large number of nodes can be deployed in the sensor field (Karl and Willig, 2007). Hence, selection on specific node for any queries will be difficult compared with the equipment with global identifiers such as in traditional network environment. Nevertheless, requesting data from specific node in wireless sensor network can be achieved using region method (Akkaya and Mohamed, 2005a). Data centric used location techniques to queries information from the specific node. The sink will send queries to the target location and nodes in the selected location will reply with the information needed. A study by Zabin et al. (2008) proposed a protocol that is claimed as a new data centric protocol which provides energy conservation and is reliable in wireless sensor networks. Reliable and energy efficient protocol (REEP) has been proposed to provide path selection with energy saving in data centric protocol. Basically, REEP was designed based on existing routing protocol for sensor network which is directed diffusion (DD) where the data requested by the sink is based on interest on named data which is called attribute-value pairs (Intanagonwiwat et al., 2003).

REEP consists of 5 important elements where each of the elements plays an important role whether on the sink node or source/intermediate nodes. REEP assumes the network topology as each network communicates between their neighbors and is only considered as multihop communication. The elements are:

Sense event: A query which is executed by the sink node to initiate sensing process to all nodes.

Information event: In responding to the sense event, the source node will generate the information which contains the location of source node and the type of object data.

Request event: Sink node will generate request event once it receives the information from the source node. A path will be created by this event to send the real data from source node.

Energy threshold value: To select which node is to participate on transmitting the real data. If the node energy is below the threshold value, the node will simply reject it.

Request priority queue (RPQ): The element in each node which is responsible to establish a path setup where it needs to select their neighbor based on the information event list.

Using these five elements, REEP consists of three phases in constructing routing path for data transmission from the source to the sink node. Figure 8 illustrates the phase processes which are the sense event propagation, information event propagation and request event propagation (Zabin et al., 2008). In sense event propagation, the sink node will be initiated with a query from the user to request specific data. Each sense event initiation will include the location of sink node, timestamp and the duration. Sink node generates the sense event and broadcasts to all its neighbors where node A acts as a sink node and broadcasts its sense event information to the neighboring nodes. Node B receives the sense event and activates its sense device to collect data from its sensing range. The received sense event by node B is checked with its cache to confirm whether the sense event is new based on the timestamp given by sink node. Each node will save the current sense event and overwrites the previous sense event. Node B will also send the sense event to all its neighbors which are C, D and E. Information event propagation is to send information to the sink node which consist the node sensing information. Node D sends its information event to the sink node where node D broadcasts to all its neighbors. Request event propagation will create a path for routing where in request event propagation; each node will be evaluated of their energy threshold to validate whether the node is ready to participate in routing path. REEP considers the energy in energy threshold value where each node is examined whether the energy value is less than the threshold or not. If the result shows the value is lower than the threshold, the nodes will be exempted from taking place as a route path in routing selection. The problem arisen from this scenario is the energy problem which is only considered on the current status energy value in sensor nodes. Thus it does not focus on how to reduce the energy consumption by each sensor node.

The energy threshold is an application dependant where it only looks into the sensor nodes itself and does not evaluate the route path selection (Zabin et al., 2008). An enhancement on the protocol can be figured out on how to minimize and manage the sensor nodes in terms of use as a routing path. In sink node selection, REEP does not clarify how it is being selected by the user and it could result on frequent select on node as a sink node. A study by Shah and Rabaey (2002) demonstrated that energy is reduced when using a sub optimal path occasionally. The approach focused on how to produce a network survivability which was suggested by Shah and Rabaey (2002) as a performance metric in routing protocol for wireless sensor networks. Energy aware routing (EAR) has been proposed to achieve the performance metric using a proactive protocol approach and directed diffusion (Perkins and Royer, 1999; Intanagonwiwat et al., 2003). Nevertheless, EAR does not adopt a concept like AODV does, which tries to find a single optimal path for routing process. EAR is different from AODV where the protocol does keep a set of number routing paths which is considered as efficient path and select one of the paths from the list. Hence, it proves that EAR protocol targets to consume energy more equally among sensor nodes. EAR implementation is split into two focus points which are addressing and routing. EAR is considered as data centric protocols since it adapts directed diffusion protocol (DD) addressing scheme (Intanagonwiwat et al., 2003) in addressing method where it uses name-attribute concept. In routing, EAR has three different phases when selecting multiple paths which have low energy consumption. Setup phase is the important phases since it considers how the energy reduction is being executed while finding the entire path existing from the source to destination and also to calculate their energy cost. The energy cost calculation is as follows:

$$\text{Cost}\ (N_{j,}N_i) = \text{Cost}\ (N_i) + \text{Metric}\ (N_j,N_i) \qquad (1)$$

This metric of energy (1) has been adapted from Tassiulas (2000) where energy is calculated based on this equation. The problem arisen in EAR is the processing in sensor nodes since each path needs to be calculated to find the energy cost. Since the sensor node has limitation in energy, to do many processes instead of routing selection and sensing information are not relevant. Furthermore, EAR uses reactive concept where it constructs a routing table to maintain the routing path for low cost energy. This could lead to high consumption in memory and processing power for sensor nodes. A study by Junyoung et al. (2009) and Park et al. (2006) had proposed energy aware routing for real time (EARQ for industrial environment wireless sensor networks. The method approach focuses on reliable delivery since real time requirements need a reliable communication. Considering energy as a main problem, EARQ calculates a probability to estimate the path energy to be consumed where it adapts EAR protocol for energy measurement. As EAR is considered as having more processing power consumption, EARQ takes reliable communication as an important value in industrial sensor network environment. Hence, EARQ has a capability to switch its mode for energy saving or reliable communication. EARQ is an extended version of EAR-RT where EAR-RT uses overhearing as a method to exchange the information between nodes for energy awareness techniques (Park et al., 2006). Sensor protocol for information via negotiation (SPIN) is one of the earliest protocols proposed in data centric protocol (Kulik et al., 2002). SPIN protocol is generally similar with directed diffusion (DD) proposed by Intanagonwiwat et al. (2003) where DD is an improvement protocol from SPIN. The only difference between them is the way of requesting the information from sensor nodes. In SPIN, sensor nodes will advertise the type of the data they have to all neighboring nodes and the interested nodes will request it (Akkaya and Mohamed, 2005a). Instead of the sensor nodes sending the information on what data it has, DD uses a sink to request any interesting data from the source sensor nodes by broadcasting the request to the neighbors. Data query protocol with restriction flooding (DQPRF) was proposed for improving the directed diffusion protocol which intends to restrict the flooding concept in sending the interest to sensor nodes (Yan-rong, 2009). DQPRF uses a level of cache in sensor nodes for eliminating the flooding concept by checking the level of neighbor’s cache to validate whether the interest has been forwarded to it previously. DQPRF selects the route by checking each node cost transmission to find the high residual energy on the sensor node as the route path.

The elimination technique aims to reduce the traffic but the packet loss should be considered as the cache level of validation cannot guarantee if the request has been forwarded previously as query based protocol is based on the attribute value interest. As DQPRF aims to use the high residual energy, it does not concern about the route cost where selecting the lowest route cost can reduce energy consumption in sensor nodes. The data-centric approach aims to retrieve information based on the data interest at specific locations. As this issue has become a limitation on the data-centric where sink node does not have any information on the specific location of the interest information, dynamic data centric routing and storage mechanism (DDCRS) has been proposed to overhaul the problem (Li-Ling et al., 2009). DDCRS uses a multi-sink concept and data storage mechanism to reduce the flooding for interest dissemination. As the share-path routing mechanism has been used for the proposed method, it reduces the energy consumption in sensor nodes for transmitting packet in selected route. A pheromone approach has been proposed for data-centric protocol for transmitting the packet in high pheromone level (Brandl et al., 2009). Pheromone based routing strategy (PRS) aims to consider the actual energy status of the neighboring nodes before transmitting the packet to the neighbors. The energy status cost considers the received signal strength, the current buffer and the energy status of the neighboring nodes. Location information in sensor nodes is one of the important elements in the data centric routing protocol where the location gives significant information about the interest information on sensor nodes for route discovery. Row construction routing mechanism aims to eliminate the usage of the location information for route discovery in data centric protocol (Yansheng et al., 2009). The sensor nodes are grouped into three important rules: firstly, the nodes are distributed among rectangular area; secondly, the sensor node has the ability to distinguish the neighboring node angle and thirdly, the nodes in boundary area know which boundary they are located in. For routing procedure, the proposed protocol used the shared information in the row information for connecting the row with the other row. This is done by the link node; the node in the edge row communicates with the first node in other row.

As mentioned earlier, SPIN is one of the pioneer protocols in data centric protocol where it disseminates the packet by negotiation based on neighboring nodes. A modified SPIN (M-SPIN) has been proposed by adding the distance discovery using hop count measured by the sink node (Rehena et al., 2011). M-SPIN sends a startup packet for hop count process until it reaches the destination of interest where the count of hop from the sink is finalized in the destination node.

Hierarchical routing protocol

In data centric protocol, each message will be broadcasted to all their neighbors; similar with flooding concept. Hierarchical protocol uses clustering concept to enable multi-hop communication within the nodes cluster (Akkaya and Mohamed, 2005a). Instead of sending message around the sensor nodes, aggregation and fusion method are used in hierarchical protocol to reduce the number of data transmission to sink nodes. These features have one main purpose; reduce energy waste. The purpose of these functions is to collect data from all sensor nodes in the same cluster and send it to the cluster head for the next process. Network clustering technique purposely to handle the scalability problem is the network where a high number of participants in network can cause a low performance in the network communication (Karl and Willig, 2007). Clustering is one of the methods to overcome these issues where wireless sensor networks environment faces a similar problem when dealing with a large number of nodes (Karl and Willig, 2007). Hierarchical protocol has been a prevalent study among researchers for the past years (Manjeshwar and Agrawal, 2002, 2001; Younis et al., 2002). Low-energy adaptive clustering hierarchy (LEACH) was among the earliest research to use clustering method for energy efficiency in routing protocol for wireless sensor networks (Heinzelman et al., 2000). There are two important issues arisen from the studies: firstly, LEACH should have the ability for fault tolerance in node failure where the protocol should recover the failure while maintaining the energy management. Secondly, LEACH capability on performing aggregation method is a must where the studies have mentioned that the bandwidth capacity for sensor networks is limited thus to reduce bandwidth consumption, aggregation is needed.

LEACH protocol was designed with three key features addressed by Heinzelman et al. (2000):

i) Node location is localized with coordination method for node control and cluster set-up.
ii) Cluster head is rotated among their clusters.
iii) Aggregation method for reducing the communication among the nodes.

LEACH process starts with the entire nodes organizing themselves through the clustering algorithm to form a cluster where one node will be elected as a head node or cluster head. Energy will be depleted more if the cluster head is fixed into one node, thus LEACH has the ability to rotate the cluster head among the nodes in the local cluster. LEACH protocol uses aggregation method to gather all information from the sensor nodes in the local cluster where the cluster head will collect the information

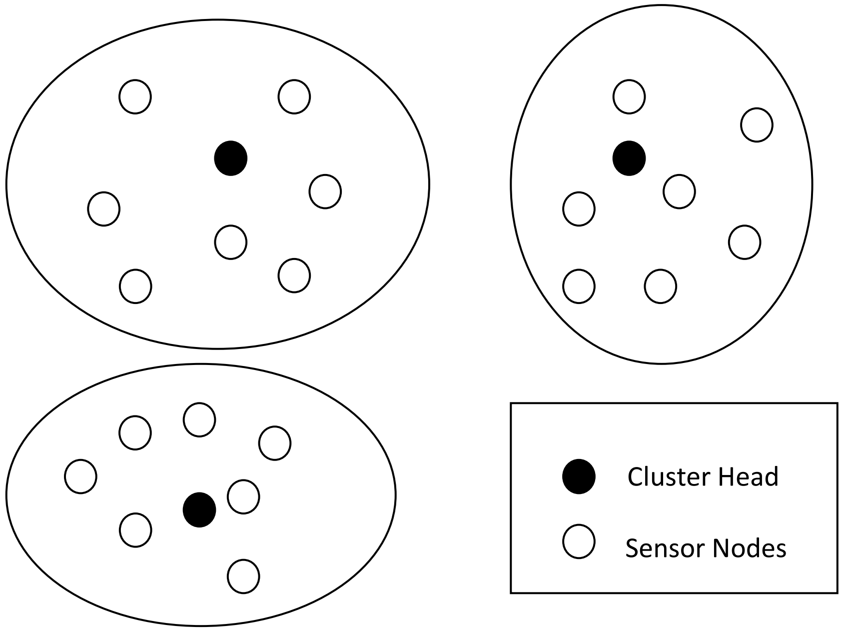

Figure 9. LEACH clustering with a cluster head.

for sending to the base station. LEACH protocol design can be divided into three different views which are nodes clustering, data gathering for aggregation and cluster head rotation. In node clustering setup, each sensor node will select which cluster they belong based on the distance between the nodes and cluster head. The process needs the cluster head to broadcast a message to all its neighboring nodes which alerts them that it is a cluster head. One of the main advantages of the clustering method in LEACH is there is a schedule for each node in the luster created by the cluster head where the schedule is to set a time cycle for the nodes to turn off the transmitter if there is no activity in the cluster. Data fusion or aggregation is to compact the data in cluster head for sending to the base station when all the information are being gathered from the sensor nodes in local cluster. The most important part in LEACH cluster head is the way it handles the rotation among the nodes for cluster head elects. Nodes are to elect by themselves based on the energy remaining in the nodes and the probability given (Heinzelman et al., 2000). In Chamam and Pierre (2009), LEACH concept has been used for achieving the energy efficiency in routing protocol where it uses LEACH feature which is cluster-based, sensor duty-cycle (sleep mode, awake mode) and cluster head selection as depicted in Figure 9. According to them, energy conservation should be implemented into five different stages mentioned by Chamam and Pierre (2009):

i) Scheduling process for sensor nodes in terms of sleep and active modes during the time given.
ii) Routing protocol with energy-efficient algorithm (clustering and data aggregation).
iii) Transmission control management.
iv) Data compression.
v) Efficiency in MAC layer for efficient channel access and data link layer for retransmission process.

The authors have used stage one and two as their level of research where they are to try extending the sensor lifetime with a proposed method. The study is to propose a plan for clustering method in routing protocol where it uses the coverage constraint as the problem. The paper does not design the protocol itself; it merely proposes a plan for setting up the sensor nodes using the coverage constraint, routing and clustering method. The concept of clustering for the proposed planning mostly is taken from LEACH protocol concept but the plan uses coverage constraint where LEACH does not concern the coverage constraint where it can cause overlap sensing within the same cluster (Chamam and Pierre, 2009). Energy aware routing in cluster base was proposed by Younis et al. (2002) where the approach uses a gateway node which is equipped with high energy device to act as a cluster head for gathering all information sensed by the sensor nodes as shown in Figure 10. Three functions of the gateway node are: to set a route for sensor nodes, monitoring the network latency in local cluster and managing the medium access by the sensor nodes. Information sent by the sensor nodes to gateway node will be sent to the base station by the gateway node. The main focus for the method is to extend the lifetime of the sensor node while minimizing any node failure in

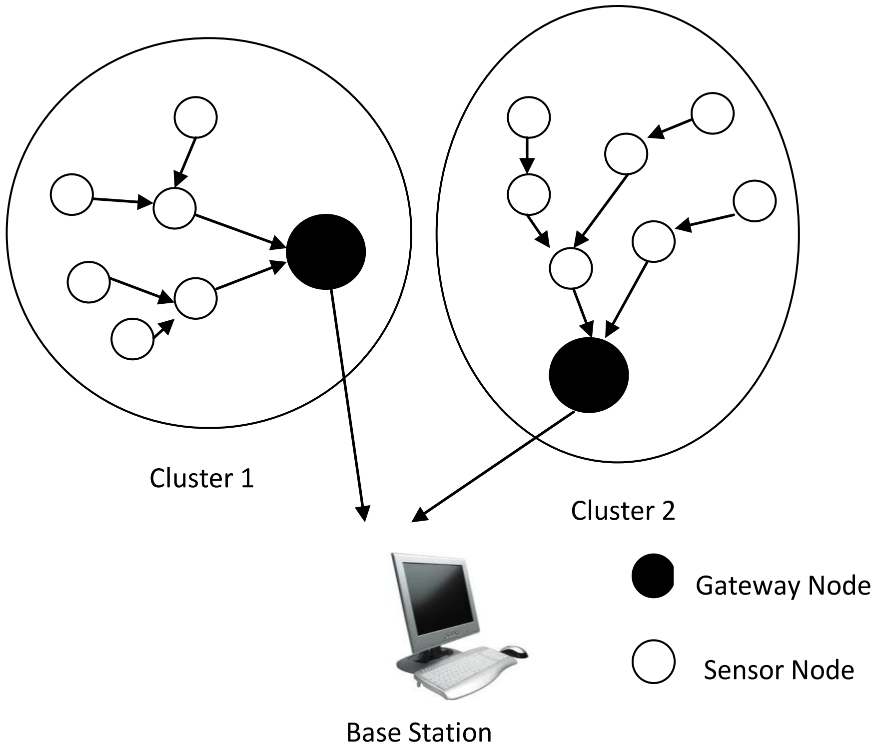

Figure 10. Clustering with gateway node mechanism.

particular cluster. This can be achieved where the protocol design focuses on the topology design and message routing. Hence, route setup in each cluster is established with centralized setup in the gateway node. The entire path for routing is managed by the gateway node where routing table is constructed after the energy evaluation on each path has been done. Less transmission is one of the advantages of the design protocol. Since the gateway node is responsible for the route setup, processing sensed data (aggregation, data fusion) and sending the process data to the base station, energy usage in each sensor nodes can be reduced as the transmission is less. Clustering makes the sensor nodes communicate with others only within their local cluster and it reduces multi hop count for data transmission.

The problem arisen here is the distance between base station and gateway node where the author has set the distance which should be close with each other, as it would cause high energy consumption for gateway node if the distance is farther.

Energy preserve method in reliable routing protocol for wireless sensor networks

Deadline delivery is critical in specific application such as health monitoring where a periodic monitoring is an approach to ensure the critical data is well received. Critical data needs to be sent to the receiver in a given time; a deadline, where it is one of the requirements of real-time environment. A deadline will be given in the specific application which the deadline is a measurement for any data transmission to arrive (Junyoung et al., 2009). In reliable communication, instead of deadline, successful transmission rate needs to be high since it guarantees the data transmission to be received by the receiver (Mahapatra et al., 2006; Martirosyan et al., 2008). As mentioned earlier, sensor nodes constraint on resources causes the limited capabilities such as in energy, low processor power and limited transceiver range communication. Hence, these limitations contribute timing constraints in wireless sensor networks for end-to-end communication deadlines (Lu et al., 2002). In wireless sensor networks environments that require time-base requests such as fire alarm, hazard detection and health monitoring, time constraint makes the reliable communication becoming crucial in data delivery process. Each type of application or data in wireless sensor networks has a different type of requirements in a deadline for data delivery, such as the alarm event which is considered as high time constraint where the protocol needs to deliver the data event in time given; as a request application for temperature room does not have time constraint since it is a non-crucial event but still needs to be delivered to destination. Hence, the reliable communication requirements can differ as in the application or data types based on the criteria of the event itself.

As mentioned earlier, multi-hop communication is a type of communication which is adapted into wireless sensor networks environment where this type of communication is identified to preserve the energy in the sensor nodes since it can reduce the energy consumption where nodes do not have to transmit the data in long distance (Giuseppe et al., 2009; Karl and Willig, 2007). As the deadline time for data delivery is a focal issue in the research, the mechanism in multi-hop communication could cause delayed transmission since multi-hop communication is time consuming where the data goes to one node to another before reaching the destination. Protocols for wireless sensor networks should support deadline delivery where it must minimize the packet loss ratio which is one of the metric performances for measuring the packet received in destination in end-to-end communication (Lu et al., 2002). Junyoung et al. (2009) considered the industrial environment as their domain where real-time requirements constraint needs to be solved for end-to-end delivery. Delay in delivery data can cause industrial application to be halted, resulting to a failure on the entire functions of the application. As resource constraint in sensor nodes has been highlighted by the authors; the reliable communication is critical in industrial application for wireless sensor networks, thus designing the protocol with reliability is needed. Reliable communication has been considered in the message as a protocol has been proposed to guarantee a periodic message between sensor nodes in the environment which requires a control action for sensor nodes (Myung-Kyun and Hoai, 2010). According to Ekici et al. (2006), an application that requires sudden response such as health monitoring needs a reliable and time-base delivery as the main capabilities in such application. They have mentioned that this type of application has some characteristics which need to be focused when designing a routing protocol with reliable communication addressed by Ekici et al. (2006):

Real-time requirements

Depending on the application, real-time is crucial when the application requirements set a deadline for transmission over the sensor nodes. This research uses static sensor nodes environment, thus deadline can be fixed at all times in sensor nodes.

Reliability requirements

The environment event makes the reliability on sensor nodes become relevant where reliability can be considered low if the event does not trigger any alert but it will become high if the alarm needs to be triggered. There are a number of researches that have been done for designing a method in routing mechanism for wireless sensor networks where real-time is the requirement for the research. Among the studies, SPEED is recognized as the earliest protocol design for real-time environment (He et al., 2002). SPEED has been designed into three different types of real-time communication which are real-time unicast, real-time anycast and real-time multicast (He et al., 2002). These requirements were derived from a main function in sensor networks which is the data delivery. Hence, SPEED has the capabilities for real-time guarantee which uses a feedback control and stateless algorithm. SPEED implements stateless approach where the protocol does not store any previous information for further communication which it could literally consume high memory usage in sensor nodes. In achieving reliable communication in SPEED protocol, a beacon message which contains node receiving delay will be sent by each node to their neighbors. The message will be sent periodically to each node for updating the nodes status since the beacon functionality is for node failure detection process (He et al., 2002). The delay will be a measurement for each node where each node will be checked periodically whether its neighbor has not sent their beacon message which the nodes will eliminate it.

MMSPEED is an extended work from SPEED protocol where it is a multi-path reliable communication which provides two advantages in quality domain; timeliness and reliability (Ekici et al., 2006). MMSPEED has the capabilities of achieving these two aims which are a guarantee on reliable communication with timeliness and sensor localization without topology information from neighbors. MMSPEED uses geographical routing for adapting mobility and scalability in sensor nodes where the protocol does not have any information about the location of sensor information. MMSPEED assumes the sensor nodes are equipped with GPS functionality for the localization process. As delivery is met in a deadline given, MMSPEED uses SPEED approach where MMSPEED provides a guarantee of reliability on multiple communications rather than a single communication. SPEED and MMSPEED protocols have given a significant impact on the reliable communication in real-time environment where both of the protocols ensure the packet delivery is met on time given. This protocol uses delay as the measurements for the packet selection in routing the establishment where the delay is calculated and measured in probability method. RAP is an architecture which is designed to provide convenience, high level query and event services with the help of packet scheduling approach (Lu et al., 2002). RAP aims to handle a communication scheduling instead of using multi-hop communication between each sensor nodes where a large number of sensor nodes are distributed. This approach has a difference from SPEED protocol in achieving reliable communication for wireless sensor networks where SPEED uses the calculated delay by sensor nodes as their main function for reliable communication rather than scheduling the communication in sensor nodes (Lu et al., 2002; He et al., 2002). RAP is designed for unicast communication where communication occurs between the sensor nodes and the base station which focuses on the real-time issues with overload problem. Hence, RAP uses location addressed protocol (LAP) for the communication protocol between the sensor nodes and base station. Several studies on reliable communication do not concern the less energy constraint in sensor nodes where nodes have the least resource in all energy aspects.

REEP which has been explained previously was designed initially for reliable communication instead of energy efficient routing in data-centric environment (Zabin et al., 2008). REEP considers the node failure and fault tolerance as a component for reliable communication where the protocol needs to handle the node failure if the energy has been depleted in route path establishment. REEP handles the node failure with node replacement method where the neighboring node which still has the information received by its neighbors will take place to replace the depleted nodes. This approach is considered as fault tolerance where the protocol has the ability to handle the miscellaneous. As this method is proven to provide reliable communication in this protocol, real-time requirements have not been a concern in data delivery deadline. REEP can overcome the network failure caused by the node failure but this capability does not provide any reliability in real-time requirements. Figure 12 shows how the failure node will be substituted by other neighboring nodes. Node A has been requested for information by node D where node A tries to establish a routing path. In the middle of the process, node C has informed its energy threshold to drop and cannot be selected as the routing path for transmission. Node B receives the alert and changes the next neighboring node as an intermediate node which is node E. The fault tolerance approach by REEP would guarantee a secondary path if the first established route path contains a failure node. EARQ protocol which has been explained previously provides real-time requirements in deadline as for reliable communication requirements (Junyoung et al., 2009). Deadline and reliability in EARQ are determined by the user and being used for selecting the nodes for path transmission based on the constructed routing table.

In the constructed routing table, a node for selection path is selected using the 3 rules for fulfilling the deadline given mentioned by Junyoung et al. (2009):

i) Node is selected from routing table based on the deadline given.
ii) Probability is calculated based on the selected node.
iii) The next node is selected randomly based on the calculated probability.

These basic rules are used for the algorithm in EARQ for sending two similar packets in the two different paths to achieve the reliability of data delivery. EARQ uses the network characteristics on density of the size network which can cause a delay in data delivery for selecting deadline consideration. To achieve this, EARQ simply divides the space of sensor nodes and sink nodes into fixed region, literally in small area. Hence, the rules that will be set for each region are:

i) A minimum of a sensor node in the region.
ii) The distance must be equal with the radio range between two different regions.

With these rules, the expected delay can be calculated where these rules can derive the maximum width of the region to obtain the minimum number of hops to the sink. Hence, the delay can be obtained from the expected sensor in the region whereas in selecting the deadline, the expected delay value will be used for approximating the deadline. EARQ protocol is fully dependent on the constructed routing table based on the probability calculated on establishment process. Sensor nodes constraint in processing power and low-energy can affect these processes as finding the probability and expected delay and deadline are high resource consuming in sensor nodes. Multi path routing has been proposed in reliable energy routing protocol (REAR) for reliable data delivery in wireless sensor networks (Kee-Young et al., 2007). Furthermore, REAR added DATA-ACK as an additional message for successful transmission in data delivery to provide a reliability communication function. The protocol establishes a secondary path for a backup to overcome any node failure in the main path for data transmission as this function is called multi-path communication. Modified AODV for wireless sensor network (MAW) has been proposed for energy efficiency with reliable communication and lightweight protocol for unicast wireless sensor networks (Patel et al., 2009). The protocol aims to improve the data centric approach protocol where it uses the same route for transmitting the data. The protocol has been designed based on Ad hoc on-demand distance vector (AODV) where it has been designed for mobile ad hoc networks routing protocol. MAW is designed to focus on unicast communication where the source will find a suitable route path for transmission as similar with AODV protocol.

There are some differences on features which have been highlighted by the authors, addressed by Patel et al. (2009):

i) MAW has a capability for finding the shortest path between two nodes rather than discovering a path.
ii) MAW protocol message packet length has been compacted for adapting the wireless sensor networks environment.
iii) Routing table for MAW only stores information about the neighboring nodes rather than the whole group of networks.

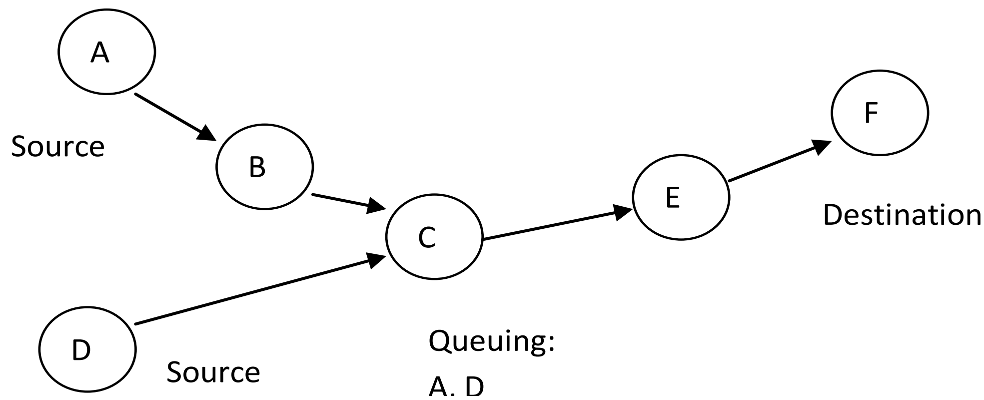

Figure 11. Velocity monotonic scheduling (VMS).

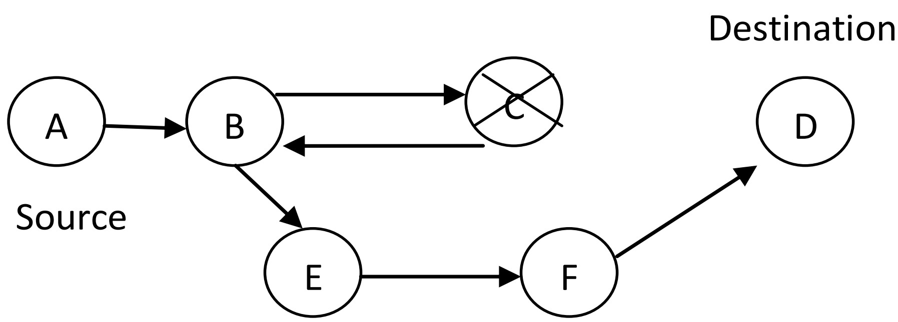

Figure 12. REEP node failure recovery path.

iv) MAW has node level acknowledgement function where the node provides information about the level of energy for reliable communication.
v) As each node has the information of its neighboring energy, retransmission process can be executed where the node will select other neighboring node based on the routing table.

MAW protocol has been proposed to improve the number of successful transmissions in wireless sensor networks. Resource constraints such as memory and energy have been well used for adapting MAW protocol. As MAW provides unicast communication, it does not provide high energy efficiency since the sensor needs to be active for most of the time period. Reliable communication was achieved by MAW without considering the deadline time of the delivery. Hence, real-time environment is not a concern in the proposed protocol.

Packet scheduling

Velocity monotonic scheduling (VMS) is a communication schedule for RAP which can be considered as a main function in RAP for real-time communication guarantee (Lu et al., 2002). Packet scheduling is a main component identified by the authors for real-time environment especially in deadline requirements for packet delivery. Figure 11 illustrates the velocity monotonic scheduling. As node A sends information to node C through intermediate node B, simultaneously node D sends the information to node C. VMS will determine the packet priority to put in the queuing table where VMS uses deadline-aware and distance-aware approaches for scheduling the packet in sensor nodes instead of using first-come-first-serve (FSFS) in which VMS prioritizes the packet based on the requested velocity (Lu et al., 2002). In deadline-aware, the packet will rely on the deadline given where the priority is higher if the deadline is lower. Similar to deadline-aware, distance-aware considers the distance of the source packet as a main value to prioritize the packet where the priority is higher if the distance was farther. Hence, VMS guarantees reliable communication in real-time where the packet is prioritized based on the higher requested velocity. Packet scheduling can perform data delivery in timely manner since the scheduling is

Table 1. Communication mechanism in wireless sensor networks.

Protocols	Energy efficiency					Reliability						Real-time (deadline)
	Multihop	Flooding	Clustering	Location based	Routing table	Fault tolerance	ACK	Re-transmit	Delay	Scheduling	Multiple data delivery	
REEP (Zabin et al., 2008)	√	√				√						
RAP (Lu et al., 2002)					√					√		√
EARQ (Junyoung et al., 2009)	√				√				√		√	√
MAW (Patel et al., 2009)	√				√		√					
SPEED (He et al., 2002)	√			√					√		√	
REAR (Kee-Young et al., 2007)	√				√		√					
Reliable message delivery (Myung-Kyun and Hoai, 2010)					√		√		√			
MMSPEED (Ekici et al., 2006)	√			√					√		√	√
TEEN (Manjeshwar and Agrawal, 2001)			√									
LEACH (Heinzelman et al., 2000)	√		√									
SPIN (Kulik et al., 2002)	√	√										
EAR-RT (Park et al., 2006)	√				√				√		√	√
Directed diffusion (Intanagonwiwat et al., 2003)	√	√										
Energy aware (Shah and Rabaey, 2002)	√				√							
APTEEN (Manjeshwar and Agrawal, 2002)			√						√			
Energy-aware and context-aware (Akkaya and Mohamed, 2005b)			√									

based on the packet criteria based on the deadline and distance of the packet, depending on the scheduling algorithm priority. In real-time environment, the urgency of the packet is being considered as critical where the deadline given is low rather than un-urgency packet. Hence, packet scheduling algorithm needs to be well structured for performing the scheduling process. The problem arise from this method is the resource constraint in sensor nodes especially in processing power and energy consumption. As scheduling occurs in the same node constantly, it can cause the energy to be depleted, thus affecting the network performance especially in delay.

PacketOPP has been proposed for wireless mesh networks where it uses packet scheduling method to assign high priority in opportunistic routing concept (Bruno et al., 2010). The packet scheduling in PacketOPP prioritizes the packet based on the opportunistic gain (potential throughput) calculation.

CONCLUSION

The emergence of wireless sensor networks technology has given significant impact on the information technology environment due to its low cost and small size in the devices. Monitoring application is one of the high prospects in terms of usage on wireless sensor networks technology. Health organization, military, industries and animal habitats were examples of environment which depend on wireless sensor networks to handle their applications. In devices aspects, wireless sensor networks require literally small sensor nodes where to be distributed along the area of application. The nodes are cheap and literally small in the size compared to other communication devices such as PDAs and mobile phone. As the size of the nodes is the main factor for a limitation from fundamental communication devices (PDAs, mobile phone, notebook), thus the criteria on limitation should be the focus in designing wireless sensor networks application. Physical resources are a critical element for any devices which in communication devices, the resources include the memory, processing power and energy. These elements have been recognized as constraints on wireless sensor nodes capabilities due to the size of the sensor node itself (Karl and Willig, 2007). Hence, a number of previous works have focused on these constraints for designing the communication and information processing elements for wireless sensor networks. These two elements: communication and information processing were identified as crucial processes in wireless sensor networks environment where it is related with the constraints mentioned. Researches in communication elements have been focusing on managing the communication resources for data delivery process. Communication process has been identified as highly resource consuming especially in energy where the data transmission contributes high energy consumption if the resource is not well managed (Giuseppe et al., 2009). There are two elements of communication for wireless sensor networks application: routing mechanism and media access control (MAC) protocol.

In previous studies, several previous works for energy perspective issues have been briefly described on both elements. Most of the studies have proven that their methods improve the energy usage in terms of network lifetime such as the time when coverage is lost between the sink node and source node and average of energy consumption in each task. In information processing elements, the previous studies have shown that clustering approach can reduce the energy expenditure when merging all the information from the nodes into one cluster head which is responsible to process it and deliver it to the sink or base station. The limitation of sensor nodes usage for processing information has given a better energy consumption management which results to the sensor nodes lifetime to increase. Having the energy efficiency in designing the communication method for wireless sensor networks has not been consider as a perfect application. Several environments such as health monitoring, hazard detection and military depend on the successful data delivery to ensure the critical data successfully received. In communication environment, reliability is one of the performances to guarantee the data delivery. Hence, a wireless sensor network requires reliability to ensure the communication delivers the data successfully. In several cases, timing constraint was one of the issues in designing the reliable communication, as certain environments such as alarm detection depends on the deadline for data delivery. A previous research has a mixed approach on real-time perspective which does not affect the physical resources if real-time environment is not a priority. Nevertheless, several researches have highlighted the real-time as a basic requirement for the current wireless sensor network environment, thus designing the communication mechanism for wireless sensor networks must achieve the deadline in data delivery.

Table 1 gives a general overview on the several previous methods for communication mechanism which aims to manage the limited physical resources in sensor nodes for wireless sensor networks application.

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