Chapter 1
Envisioned Network Architectures for IoT Applications

P. Sarwesh, N. Shekar V. Shet, and K. Chandrasekaran

Abstract Internet of Things is the auspicious technology that connects different internet enabled devices in single network architecture. IoT contributes effective service in various applications such as industrial automation, health care sectors, and home automation. Availability of low cost devices makes IoT as innovative paradigm in large-scale wireless network research. Challenges in IoT applications vary from each other. For example, in smart grid applications QoS is more important, whereas for land slide monitoring applications, energy efficiency and reliability are the major requirements. Thus, in this chapter, we come up with various network architectures that are suitable for IoT applications. The network architectures are designed by combining different optimization techniques into single network design, to satisfy specific network requirements. This chapter elaborates the major issues that affect the network performance and suitable solutions for those issues by means of efficient network architectures.

1.1 Introduction

Internet of Things (IoT) is the ever-growing network of smart devices that promotes global information sharing. In the phrase Internet of Things, the word "things" can include from small watch to big vehicle [1]. It creates smart environment in every fields such as smart city, smart health, smart grid, smart market, smart agriculture, and smart home. MEMS technology is the major reason for IoT development, since availability of low power and low-cost devices is achieved by MEMS technology. Internet enabled devices work autonomously with its features such as sensing, communicating, and computing. IoT network is the combination of

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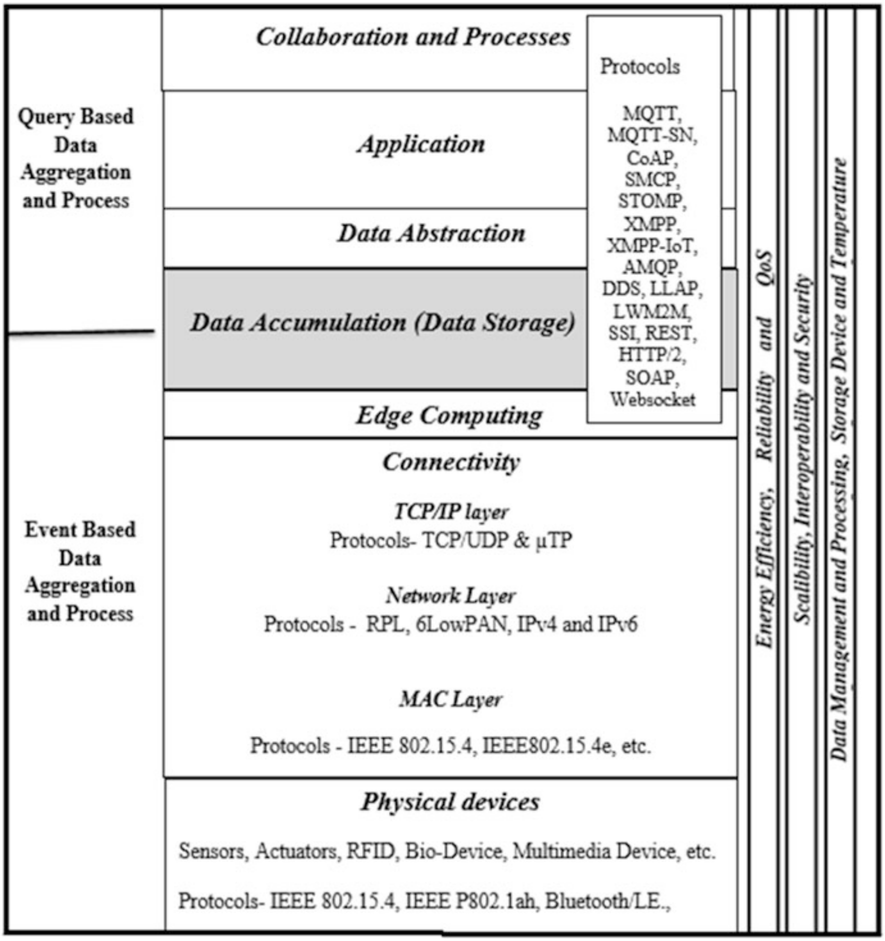

Fig. 1.1 IoT World forum reference model and its challenges

higher end devices (servers) and lower end devices (sensors). Therefore, connecting this interoperable network environment with efficient network architecture is the major challenge in IoT networks [2]. IoT is the new idea, but the technologies that required for built IoT are well matured, therefore IoT technology is conceivable in different fields. Existence of remote and wired advances with productive processing and correspondence structure encourages IoT to give powerful correspondence between machine-to-machine, machine-to-individual, individual to-machine, and so forth [3]. Internet of Things can be described as smart device network that collects the environment information with the help of IoT devices, for every applications network devices and network requirements vary, thus based on the network requirements and network challenges we designed an effective network architecture in this chapter.

In Fig. 1.1, lower layers manage event related data (occasion related data), whereas higher layers are responsible for question related data (query based data). The middle layer is used to store and recoup the information made by higher layers and lower layers. The major goals in lower layers are energy efficiency, Quality of Service (QoS) and reliability, since they handle constrained devices and low power radio connections [4]. In higher layers, data organization and data get ready are considered as genuine troubles, since they handle a gigantic piece of data. Arranging powerful and compact storage devices and controlling the temperature dispersed from higher end devices (servers) are the noteworthy difficulties in the center layer (storage layer). IoT devices in low power frameworks (IoT, WSN) routinely continue running by limited battery control, obliged preparing speed and irrelevant memory [3, 5]. In Internet, devices are connected to the electricity grid with stable power supply. However, IoT devices are usually battery sourced devices, which are unstable in nature. Web uses stable associations, for instance, Ethernet and SONET/SDH joins, whereas IoT holds low power radio connections (IEEE 802.15.4) that are lossy and precarious in nature, which says components of IoT contrast from consistent Internet.

1.2 Network Level Challenges in IoT

In this chapter, we concentrate on challenges of lower layers (Network Level Challenges). This section describes the importance of energy efficiency, reliability and QoS for low power IoT networks.

1.2.1 Energy Efficiency

Efficient energy utilization is one of the primary challenges in wireless smart devices networks (WSN, IoT, etc). Smart devices used in environmental monitoring applications as well as in commercial application are operated by battery power. In forest fire monitoring application (environmental monitoring), if the sensor battery drains out its power, it is very difficult to replace the battery. Similarly, in industrial boiler monitoring (critical monitoring), if the smart device drains out its power, it severely affects the service. Unbalanced energy utilization disturbs the network lifetime, cutback in lifetime of networks severely affects customer as well as service provider. Thus, energy is considered as one of the valuable resources in low power wireless network applications [6]. To utilize energy in efficient way factors that affect energy efficiency need to analyze and to be prevented. Effective physical layer techniques, MAC based power control techniques and network layer optimization techniques can be the effective solution to optimize the energy efficiency in networks.

1.2.2 Reliability and QoS

Low power IoT network utilizes low power radio protocols (e.g. IEEE 802.15.4) to interconnect switches, routers and other IoT devices, which are battery sourced devices. Providing higher duty cycle protocols in resource constrained network environment is impossible, similarly providing main power lines to every IoT device is impossible. Therefore, it is understood that providing effective communication between IoT devices through unstable network links is the major consideration in IoT network design. Due to unstable network links (low power radio links) chance of packet loss is more and dynamic link variations severely affect the data transmission. Sensor devices in remote territory (e.g. landslide monitoring) might be scattered unplanned and they are little in size and constrained in battery. In such network environment, providing reliable data transfer with low duty cycle protocols is the challenging task in wireless network research. Routing process consumes huge amount of energy, for reliable data transfer routing is the key element, since efficient routing design is the major requirement in low power IoT networks [6]. Data transmission through unstable links leads to packet loss, which severely affects the network reliability and QoS. Thus, an effective network design is needed to achieve better reliability and QoS.

1.3 Factors that Affect the Network Performance

In low power wireless network, various factors affect the network performance; in this chapter, some of the major factors that affect the energy efficiency, reliability and Quality of Service (QoS) are described. Figure 1.2 describes the major factors that affect the network performance.

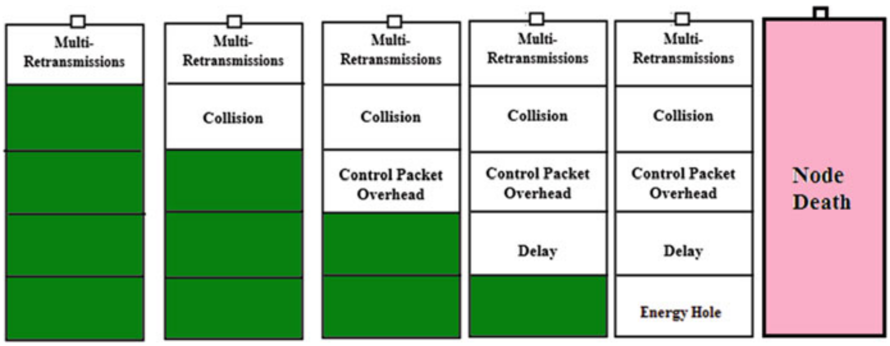

Fig. 1.2 Factors that affect the network performance

1.3.1 Energy Hole (Node Overload)

The smart devices which are close to the base station convey enormous measure of information activity. Since smart devices (sensor devices) which are close to the base station forward the sensed data of its own as well as the forwarded data of other sensors, and as a result of huge data load, nodes drain out its power in short span of time [6]. When every node near to base station coverage area drains out its battery source, communication to the base station will be blocked, which leads to network re-initialization, this problem is referred to as energy hole issue. Energy hole problem severely affects the network performance, cost and time (re-installation time). Thus, balancing energy consumption and avoiding node overload can be the active solution to avoid energy hole issue.

1.3.2 Multi-Retransmissions

In low power wireless networks, lossy and unstable links are used to connect the low power smart devices (battery sourced device). And quality of radio links that are used in low power network environment will vary frequently. Data transmission in unstable links leads to packet loss, which are the prime reason for data re-transmission [6]. Data re-transmission affects the network reliability as well as energy efficiency. Thus, avoiding re-transmission decidedly improves the network performance. Data-re-transmissions can be avoided by transmitting data in stable links (reliable links).

1.3.3 Collision

Collision is a noteworthy issue in remote system; it influences the execution and lifetime of the wireless network. Amid the information transmission from transmitter node and receiver node in specific channel, new entry of transmission signal from another node in same channel prompts collision. Collision gives rise to increase in packet re-transmission, this prompts energy wastage and huge network congestion. Increase in collision increases the network latency and degrades the network reliability and energy efficiency. In wireless network, TDMA is the suitable technique to avoid collision, but TDMA increases control overhead as well as energy utilization. Thus, an effective MAC based optimization technique is required to avoid the network collision [7].

1.3.4 Control Packet Overhead

Extra data (control packets) required for specific protocol to establish association and correspondence is referred to as packet overhead. These control packets are specified as CTS, RTS, RREQ, RREP, etc. based on protocols. These packets are the prime reason for establishing the communication, and with the aid of this information network connectivity is maintained. Therefore, control packets are fundamental need for establishing connection, but it should not exceed its limit, which severely affects the energy efficiency of the network. Avoiding excess control packet usage (huge control overhead) can improve the energy efficiency with better network connectivity [8].

1.3.5 Delay

Delay is one of the major reasons that affects the QoS of the network. Data transfer in unstable links, packet loss, re-transmissions, unbalanced buffer usage are the major reasons for increase in end-to-end delay. Thus, preventing above factors will highly prevent end-to-end delay [6].

1.3.6 Motivation

From the above discussions, it is seen that energy efficiency, reliability and QoS are the major requirements in low power IoT networks. In low power wireless network, huge amount of energy is consumed by communication unit. Therefore, optimizing communication unit highly improves the network performance. There are various techniques such as node placement technique, MAC based power control technique, MAC based scheduling technique, routing technique, TCP/IP based optimization techniques etc. to optimize the communication unit of the network. All these techniques satisfy specific network requirements, when compared to utilizing the features of single optimization technique. Integrating the features of various optimization techniques in single network architecture highly improves the network performance. In wireless network research, cross layer protocols such as EQSR Ben-Othman and Yahya [9], HAN Larzon et al. [10], XPL Vuran and Akyildiz [11], and Breath Park et al. [12] are developed by combining the features of various optimization techniques to obtain better network performance. From this observation, we designed various network architectures that integrate the features of various optimization techniques to achieve application specific network requirements.

1.4 Envisioned Network Architecture for Low Power IoT Networks

This section describes the various envisioned network architectures that are proposed for IoT applications, proposed network architectures are designed by integrating various optimization techniques in single network architecture. In this chapter, network architectures are developed for some of the popular IoT applications.

1.4.1 E-Health

Smart health applications have gained lot of attention in many health care sectors. Availability of intelligent biomedical devices, effective middle ware services and low power communication technologies (low bandwidth radio protocols) made the possibility of accessing medical information of patient, even they are in remote area. Now-a-days because of mobile telemedicine system, patients continue their regular activities [13]. IoT technology supports various e-health applications, such as wearable device and its data accessing (automatic diagnosis system), remote monitoring of elderly patients' health condition, and immediate responding in emergency situations. Smart health systems in hospitals collect the information from ECG measuring devices, EEG measuring devices, X-ray devices and store it in their database, this health information of patients can be accessed by health experts and based on the health history from smart health systems medical experts proceed the treatment [13]. Because of smart health systems, accurate health information of patients is obtained and effective health care service is provided to them.

E-health application is one of the critical monitoring applications. Constant monitoring of patients with chronic conditions and reporting to medical officer is the major task that is practiced in e-health applications. The prime components required for health care system are communication enabled devices, data acquisition boards, wireless routers and efficient server that maintain the health-related data. All these components will be connected by low power radio links and most of the wireless devices (wireless routers and data acquisition boards are operated by battery powered devices. In such network scenario, reliability is the major requirement, if data loss occurs it severely affects the e-health service. The layers that involve in reliability are TCP/IP layer, network layer and MAC layer. Therefore, we integrated TCP\IP layer and routing layer to improve the reliability of the network. Buffer level information of each node is observed in route discovery process (control packet transmission and reception). Based on the control packet information data transmission is done with respect to the buffer level of nodes. This highly balances the data traffic and improves the network reliability. In critical monitoring applications (monitoring the health conditions of patients) reliable data transfer is the major challenge. When packet loss occurs, then ACK packets are required for re-transmissions. Multi-retransmissions in network severely affect the

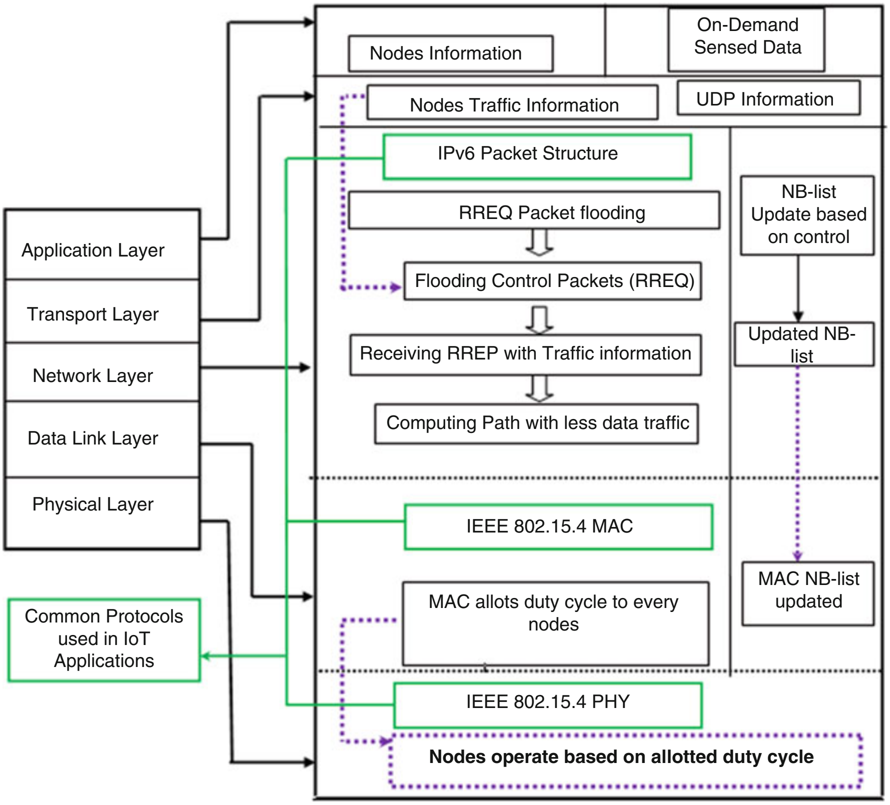

Fig. 1.3 Reliable network architecture for e-health applications

network reliability and degrade the health care service. Thus, we propose the reliable network architecture by integrating the TCP/IP layer and network layer.

Figure 1.3 describes reliable network architecture that is suitable for e-health application, it is the operational flow of proposed network model. In this architecture, features of TCP/IP technique and routing technique are integrated. Initially traffic information of network is attained by the TCP/IP technique and later routing technique utilizes the traffic information and finds reliable path for data transmission.

1.4.2 Environmental Monitoring

Environmental monitoring applications collect the environment related information (temperature, humidity, smoke, fire, etc.) and transmit it to base station. Environmental monitoring includes landslide monitoring, forest fire monitoring, flood monitoring, temperature monitoring, snowfall monitoring, irrigation monitoring, tsunami monitoring, wild life monitoring, industrial smoke monitoring, pedestrian monitoring, etc. All these applications are situated in remote area, thus devices used in these applications are battery operated. When the battery drains out its energy, battery replacement need to be initiated, frequent battery replacement in such harsh environment is impossible. In flat based network scenario, the data traffic is from sensor nodes to base station, therefore the nodes near to base station hold bulk amount of data traffic, when nodes near to base station are burdened (data traffic overload), then they drain out its power in short span of time [14]. Thus, balanced energy utilization is the major requirement in environmental monitoring applications.

Based on this observation, we designed energy efficient network architecture that integrates routing and node placement technique. The reason of integrating these two techniques for environmental monitoring applications is they are considered as the effective techniques, to improve the energy efficiency of the network. In node placement technique density of nodes are varied based on data traffic, which balances the data traffic load and prevents energy hole issue (quick node death). In routing technique energy and reliability related parameters are included to compute energy efficient and reliable path. Residual energy is considered for energy monitoring and expected transmission count (ETX) is considered to find the reliable links, therefore effective combination of these two parameters finds energy efficient and reliable route. Node placement technique takes care of data traffic, routing technique monitors energy consumption and finds reliable links. Thus, all these features are included in single network architecture to achieve balanced energy utilization in energy constrained network environment. In this network architecture, routing technique and MAC nased power control technique are both integrated in network initializing phase. The idea at the heels of this work is utilizing features of node placement technique and routing technique in single network architecture to improve the energy efficiency of the network.

Figure 1.4 describes the energy efficient network architecture for environmental monitoring applications, it is the operational flow of proposed network architecture. In this architecture, node placement technique manages the data traffic and routing finds energy efficient and reliable path, these features are integrated in single network architecture. In network setup phase node placement is implemented and in network initialization phase routing is implemented.

1.4.3 Industrial Automation

Industrial automation is making industrial systems automated by the aid of computing assisted technology and communication technology. Problems in many industrial equipment are diagnosed and reported by the help of wireless enabled industrial automation systems [3]. Of late, many industries started talking about wireless enabled automation systems in industries. Many discrete manufacturers are concentrating on implementing wireless infrastructure in industries to monitor and

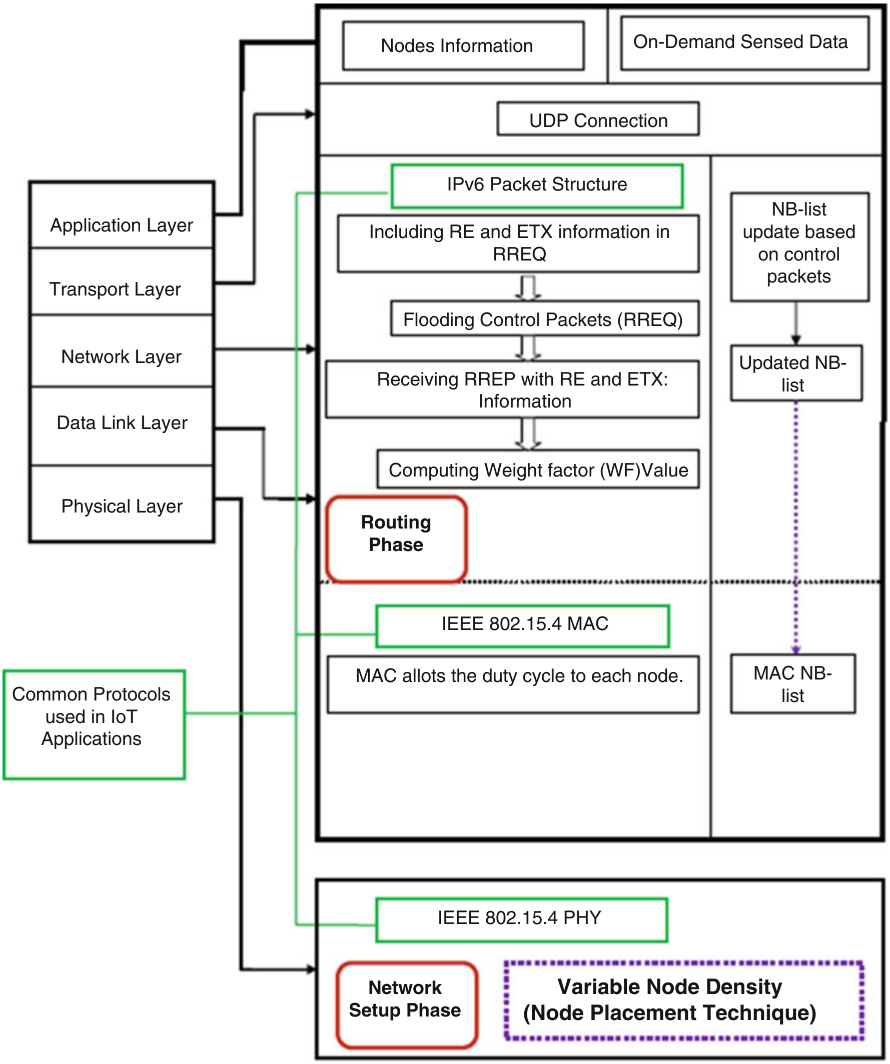

Fig. 1.4 Energy efficient network architecture for environmental monitoring applications

maintain the plants. In many industries, parameters such as pressure, temperature and flow are observed, whereas equipment related information such as equipment conditions and efficiency of the equipment are not monitored [15]. Thus, an effective wireless network infrastructure for monitoring production as well as equipment conditions is the major requirement. Implementing wired network infrastructure is also possible in industrial environment, but designing, wiring, cost of the components, etc. are difficult in wired network environment, therefore implementing wired network infrastructure is very expensive [15], whereas wireless technology is flexible in all aspects such as implementation, cost, scalability, and mobility. Wireless enabled industrial automation system provides sensing as well as actuation.

Industrial activity monitoring is also the critical monitoring applications (e.g. industrial boiler monitoring). Monitoring the working conditions of industrial instruments is the prime task in industrial monitoring applications. Therefore, reliability and QoS need to be maintained in effective way in this application. For this application, we propose a network architecture that integrates network layer and MAC layer to improve the QoS and reliability of the network. Based on the routing information transmission range of nodes is varied by MAC based power control technique. Based on this integration every node obtains its optimum transmission range. In this network architecture, routing technique and MAC based power control technique are both integrated in network initialization phase. The reason of integrating routing and MAC based power control technique is reliability and QoS related information are observed from routing technique. Based on this routing information MAC adjusts its transmission power, which says every node achieves its reliable transmission power.

Figure 1.5 describes the QoS aware network architecture that is suitable for industrial automation applications. In most of the industrial applications QoS aware data transmission is the major challenge. In proposed network architecture, QoS related information for every node is achieved by routing technique. Later, MAC based power control technique utilizes the received signal strength and adjusts the transmission and reception power, to achieve QoS aware data transfer.

1.4.4 Smart Grid

Power grid is the electrical grid that delivers electricity to various infrastructures (office, houses, industries, huge apartments, etc.). Distributing electricity from power plants to consumers in smarter way (efficient way) is referred to as smart grid. Electric power consumption of every consumers is measured by the electric meters, thus implementing smart meters in power generation as well as power distribution systems performs sensing as well as actuation to enhance the grid operation [16]. Smart devices collect the electricity related information between power generation and distribution systems and it sends these information to analytical tools for balanced utilization of power, as well as it helps in identifying issues in power distribution systems and power wastage in power distribution systems [16]. For such network scenario, power distribution should be maintained by reliable network infrastructure. Thus, we come with reliable cross layer design that integrates routing technique and MAC based power control technique to improve the network reliability. In routing mechanism, reliability related parameter called received signal strength (RSSI) is included for route discovery process, later MAC based power control technique utilizes the routing information and adjusts its transmission power based on the routing information. In this network architecture transmission ranges are adjusted based on reliability (RSSI) of the network. Thus, every node obtains

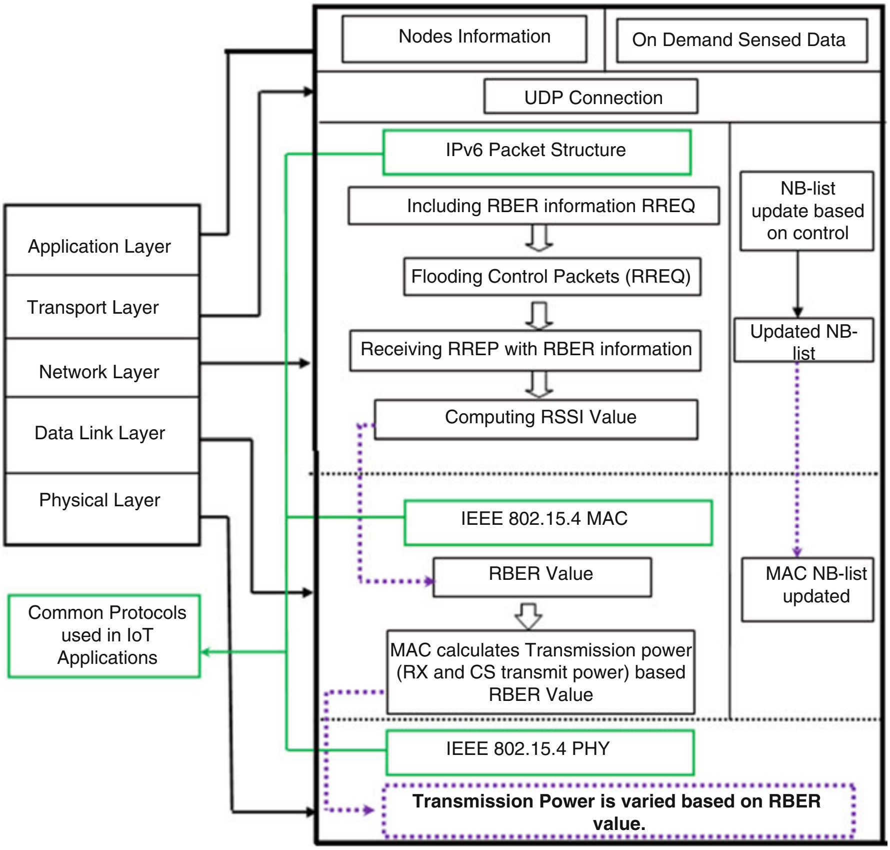

Fig. 1.5 QoS aware network architecture for industrial automation applications

its own capable transmission range to achieve reliability of the network. Figure 1.6 describes the reliable network architecture for smart grid applications. Reliability is the prime need for smart grid applications. In proposed network architecture, RSS (received signal strength) information for every node is attained by routing technique. Later, MAC based power control technique utilizes the received signal strength and adjusts the transmission and reception power, to achieve reliable data transfer. Table 1.1 describes the features of proposed network architectures.

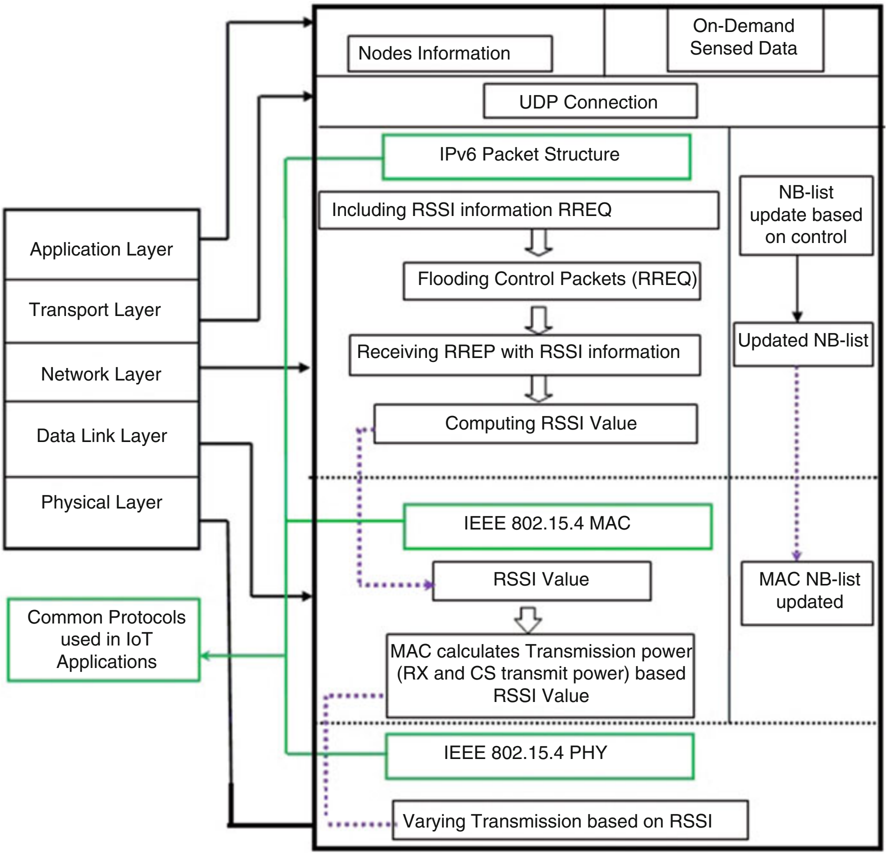

Fig. 1.6 Reliable network architecture for smart grid applications

Table 1.1 Difference between proposed network architectures

Applications	Challenges	Integration
E-health	Reliable data transfer	Network layer and TCP/IP layer are integrated
Environmental monitoring	Network lifetime and reliable communication	Network layer and physical layer are integrated
Industrial automation	QoS aware data transfer	Network layer and MAC layer are integrated
Smart grid	Reliability	Network layer and MAC layer are integrated

1.5 Suitability of Proposed Network Architectures for IoT Scenario and Network Assumptions

IPv6 address, IEEE 802.15.4, RPL (routing protocol for low power and lossy networks) and 6LoWPAN are included in network architecture to obtain suitability of proposed architectures with real-time IoT applications.

The basic assumptions of proposed network architectures are as follows:

- Sensor nodes are deployed in random manner.
- All the nodes are battery sourced.
- Nodes are aware of the routing information (energy related information and reliability related information).
- Base station is not limited by energy.

1.6 Conclusion

Internet of Things is practiced by numerous applications. Every application has specific network level issues based on their network environment. Most of the IoT applications are situated in remote environment, where battery operated devices are possible devices to collect environmental information and low power radio links are the possible medium to connect low power devices. Therefore, providing active communication in resource constrained network environment is the major challenge in low power IoT network. This chapter elaborates the resource constrained nature of IoT network and describes the issues that commonly occur in IoT network. We analyzed the major network level challenges that are faced by various IoT applications. Based on these challenges, we designed network architectures that satisfy application specific network requirements. The proposed network architectures are constructed by integrating the features of various layers together. These envisioned network architectures give the clear idea to optimize the low power IoT networks.

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