Paper

A Survey on Wireless Network Applications in Automated Public Utilities Control and Management

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Abstract—Public utilities such as water, electricity and gas are essential services that play a vital role in economic and social development. Automation of public utility services addresses the huge losses faced by the utility services today, due to non-accounting of distributed utility resources. Automation improves government revenues. The different type of architectures are proposed and designed for automated metering, control and management of public utilities like water, gas, and electricity for effective management and control of resources. The various network topologies, hardware and software architectures to automation and management of public utilities are proposed by researchers. In this paper, the different technologies proposed by various researchers across the globe are surveyed and list of issues and challenges for automated meter reading and control of public utilities is identified.

Keywords—Automated Meter Reading (AMR), Wireless Sensor Networks (WSN), Wireless communication, Short Message Services (SMS).

1. Introduction

At present, most of the houses across globe have the traditional electromechanical or digital energy, water or gas meters. These public utilities have individually managed by connected service departments. Today the billing system and control and management of public utilities are not fully automated. Presently person from the electricity or water or gas board goes to every building and takes the meter reading manually. These meter readings are used for electricity or water or gas bill calculation. It requires a large staff for reading the meters, control and manage public utilities, and eventually sending the bills to customer. A new technology named Automatic Meter Reading System (AMR) is discussed. AMR is a sophisticated system, which allows companies to collect the reading without visiting the site. As number of meter grows the manual collection of data is becomes cumbersome task and time consuming. Sometime task become infeasible if the data terminals are unreachable. Therefore, a wireless based data collection mechanism is needed. The mentioned task can be achieved by using wireless communication network. AMR is a system and process used to remotely collect electrical, water or gas meter data without the physical presence of meter readers at the user premises. With such automation, system it is possible to read multiple meters remotely at any time. AMR is also known as smart meters and associated network is called smart grid. It provides cost effective solution to meter reading service. AMR use a real time wireless communication network to connect meters with a central system.

Public utilities are essential services that play a vital role in economic and social development. Quality utilities are a prerequisite for effective poverty eradication. Increased competition in the utilities sectors in recent years has entailed changes in regulatory frameworks and ownership structures of enterprizes, in addition to business diversification and enhancing efficiency of delivery and reviewing tariffs and other sources of income collection remotely.

The authors contribution in this paper is the extensive survey of proposed electricity, water and gas meters based automated public utility control across the globe. The comparative analysis of related works with parameters which includes communication protocols, topologies, network, hardware, and applications used for automated management of public utilities is made.

In Section 2 the taxonomy of automated utility management and comparative study of related works is provided. Section 3 provides a survey of integrated solutions for utility management. Section 4 presents the issues, challenges in automated management of public utilities in present scenario, Section 5 presents future research directions and overview of proposed methodology. The paper is concluded in Section 6.

2. Taxonomy of Automated Utility Management

Recent research has developed several techniques that deal with various types of automated control and management of public utilities control at different networks. To assist in understanding the assumptions, the authors focus design and development of these techniques. In this section the taxonomy of different automation technologies used in traditional systems and survey various research on automated

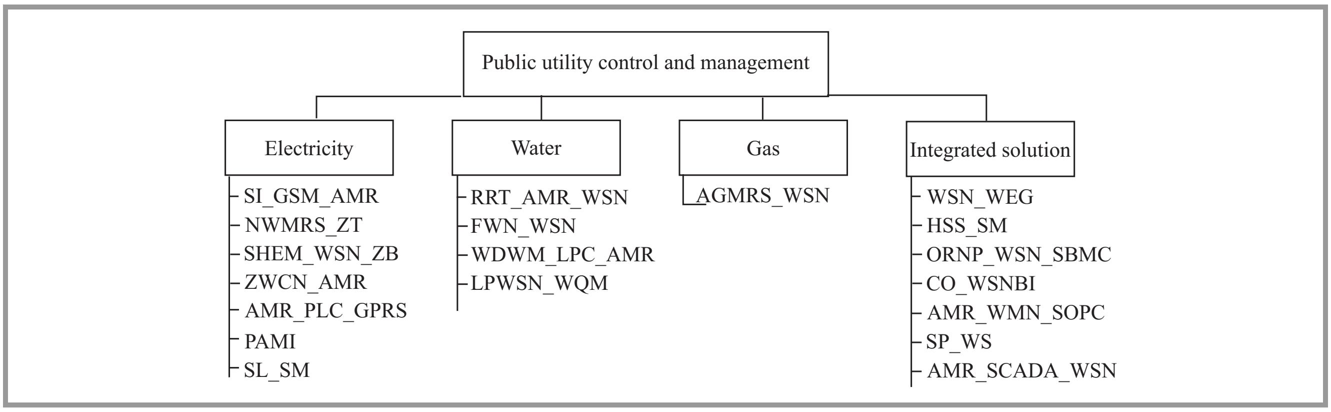

Fig. 1. Taxonomy of public utility management and control.

public utility management shown in Fig. 1 is provided. Public utility management and control mechanisms are categorized based on type of utility and applied technologies. The basis of utility classification includes: (a) electricity, (b) water, (c) gas and (d) integrated solution. Public utility management and control mechanisms can be further classified based on the technologies used.

Examples of automated electricity based utility management are:

- SI_GSM_AMR – smart and intelligent GSM based AMR system,
- NWMRS_ZT – networked wireless meter reading system based on ZigBee technology,
- SHEM_WSN_ZB – smart home energy management system using IEEE 802.15.4 and ZigBee,
- ZWCN_AMR – ZigBee wireless communication network design as an answer for last-mile problem in consumer AMR systems,
- AMR_PLC_GPRS – implementation of AMR system using PLC and GPRS,
- EEAMI – an energy efficient advanced metering infrastructure,
- PAMI – the prepaid advanced metering infrastructure,
- WDTMS_RE – the application of wireless data transmit module in monitoring system under remote environment,
- WSN_SM – wireless sensor network based smart meter.

Examples of automated water based utility management are:

- RRT_AMR_WSN – remote real time AMR system based on WSN,
- FWM_WSN – a flexible architectural framework for water management based on wireless sensor network,
- WDWM_LPC_AMR – wireless digital water meter with low power consumption for AMR,
- LPWSN_WQM – low power wireless sensor system for water quality monitoring.

Example of automated gas based utility management is:

- AGMRS_WSN – automatic gas meter reading system based on WSN,

Examples of automated Integrated solution based utility management are:

- AMR_SA_WSN – AMR and SCADA application for wireless sensor network,
- WSN_WEG – WSN in water, electricity and gas industry,
- AMR_SCADA_WSN – AMR and SCADA application for WSN,
- HSS_SM – hybrid spread spectrum based wireless smart meter,
- ORNP_WSN_SBMC – optimal relay node placement in WSN for smart buildings metering and control,
- CO_WSNBI – cost optimization of wireless-enabled metering infrastructures,
- AMR_WMN_SOPC – AMR system based on wireless mesh networks and SOPC technology,
- SP_WS_WGMS – self powered wireless sensors for water gas meter system.

Automated reading technologies are classified based on the parameters such as bandwidth, delay, reliability, etc. The reason behind classifying automated reading mechanisms based on technology is that the topological analysis gives better way of representing the utility technology to provide clarity and effectiveness. Further classification is based upon various services that every topology based technology supports. The services supported by the topology based on utility can be seen at broader way [1].

2.1. Electricity as Public Utility

A. Jain *et al*. in 2012 presented the development of Smart and Intelligent GSM based Automatic Meter Reading System, which is has capabilities of remote monitoring and controlling of energy meter [2]. AMR continuously monitors the energy meter and sends data on request of service provider through SMS. The data received from an energy meter is stored in database server located at electricity board station through SMS gateway. It is further processed by energy provider. Energy provider sends electricity bill either by e-mail, SMS or by post [3]. This system allows to the customers to pay bill online by card or by money transfer. This system helps electricity companies to take action against lenient customers who have outstanding dues. Otherwise, companies can disconnect the power and reconnect it after deposition of dues. This system also gives the power cut information and tempering alert.

L. Cao *et al*. in 2008 carried research on networked wireless AMR system based on wireless sensor networks and ZigBee technology. The paper presented the mechanism for solving the problems existed in the present meter reading system. The hardware structure of system employs WSNs consists of measure meters, sensor nodes, data collectors, server and wireless communication network [4], [5]. The mesh network topology was adopted in this design. For a short distance transmission, the data sink collects data from the meter sensors using the ZigBee [6]. For a long distance transmission system uses TCP/IP protocol from the data sink to the server. A modified routing protocol is used based on LEACH is adopted in this system.

D.-M. Han *et al*. in 2010 proposed smart home energy management system using IEEE 802.15.4 and ZigBee. This mechanism introduces smart home interfaces and device definitions to allow interoperability among ZigBee devices produced by various manufacturers of electrical equipment, meters and smart energy enabling products. It introduces home energy control systems design to provide intelligent services for users and tested in real test bed [7].

In the research of K. Marcinek in 2011 design and implementation of ZigBee wireless communication network design as an answer for last-mile problem in consumer AMR systems [8] are proposed. The main stress was given to compatibility and integration with existing AMR networks along with installation complexity. It maintains low bit error rate (BER). Real life implementation of ZigBee based energy meter reading in one of the modern estates in Warsaw was presented in this work. In this mechanism ZigBee wireless communication network design for last-mile problem in consumer AMR systems has been proposed. Author achieved results of 98% of delivered packet rate. It also said this solution provides both transparent and buffered communication independent to attached device protocol. It is proposed that, usage dedicated GSM modem with ZigBee integration board with into existing AMR systems. This solution reduces both costs and installation time. PC software allows the system owner remotely monitoring network along with modem parameters management for flexibility. Future work proposed by author concern further system functionality improvements. Usage of module with on-board application processor and external memory for implementing local buffered data read out and gaining independence from the radio link quality fluctuations or temporary inaction. Tests with 868 MHz modules are also proposed. It is indicated that the only disadvantage is in Industrial, Scientific and Medical (ISM) band has its 10% duty cycle limitation. On heavy network load, this regulation decreases the real RF data rate from 24 Kb/s to 2400 b/s, which is over 100 times slower in comparison with 250 Kb/s on 2.4 GHz band.

J. Yang *et al*. in 2011 presented an AMR system using PLC and GPRS communication [9]. Authors have studied that electricity meters installed in every household is connected to a collector through RS-485 interface. The communication between data sink and collectors is done using Power Line Carrier (PLC). The data sink is connected to master station via a GPRS accessing to Internet. It is indicated that proposed solution can be used for water and gas meters. Authors proposed an energy efficient advanced metering infrastructure (EEAMI) for meter data collection and energy management. An energy efficient Advanced Metering Infrastructure (AMI) is an AMR infrastructure with bidirectional meters. These meters are called smart meters they are connected to the gateway through power lines and gateway that communicates to the central station. The central station communicates through GSM.

Kishore *et al*. in 2012 proposed the prepaid advanced metering infrastructure (PAMI). It combines with 3G network technology [10]. This research claims that proposed technology will make the processing fast and reduce the theft of electricity. It will make people more conscious and will save electricity. Moreover, people in this mechanism can recharge their smart cards with the desired amount even at the end of the month. Future work includes using supercapacitor instead of using fixed battery inside the electronic meter and develop the system in ASIC chip. In addition, real time clock can be interfaced with the electronic meter so that when credit finishes at night or at holidays, the meter will not close the valve at that time, rather continue with negative billing and finally close the valve at working hours.

Z. Ailing *et al*. in 2004 proposed an AMR system using the application of wireless data transmit module in monitoring system under remote environment, which is low cost, high performance solution [11].

2.2. Smart Grid in Electricity Distribution

A smart grid is an electricity distribution network that combines a bidirectional power flow network integrated with a bidirectional information flow in such a manner as to facilitate various optimization and control features.

Table 1
Automation of electricity utility management

No.	Research	Protocol	Topology	Network	Hardware	Application
1	SI_GSM_AMR	SMS, GSM	—	GSM	—	Electricity
2	NWMRS_ZT	LEACH, TCP/IP	Mesh	ZigBee, IP	S344B0X	Electricity
3	SHEM_WSN_ZB	Disjoint multipath routing protocol (DMPR)	—	ZigBee, HAN	CC2420, CC2430, 8051 MCU	Consumer electronics device
4	ZWCN_AMR	ZigBee	—	WSN	—	Electricity
5	AMR_PLC_GPRS	SMS, GPRS, TCP/IP	—	PLC, GPRS	—	Electricity
6	PAMI	GSM	—	3G	GPRS modem	Electricity
7	WSN_SM	Reliable block transport (RBT)	Cluster tree	—	LPC1763 ARM, CC1120	Electricity

A key enabler for the smart grid is a distribution utility is the final touch point with residential and industrial consumers. Apart from delivering quality power to the consumer premises, it has to manage consumer expectations, environmental implications, and billing to generate revenue for the entire stakeholders in the power ecosystem. It acts as the perfect input for revenue management, energy accounting, and billing for the utility. One of the most compelling benefits of the smart grid is the promise of delivering demand management or load control. Utilities will save energy, lower costs and defer additional transmission and generation expenses with the ability to shape load and curtail load to mitigate grid events. Additionally, consumers will be able to conserve energy use to benefit from time of use or time based rate structures. Various studies have shown that these actions can give 15 to 20% savings.

Next generation power grid, uses two-way flows of electricity and information to create a widely distributed automated energy delivery network.

The smart grid in electricity distribution was discussed by X. Fang *et al*. in 2011 [12]. The three major systems were explored, namely the smart infrastructure, the smart management and the smart protection. Authors also proposed possible future directions in each system. For the smart management system, the authors presented various management objectives, such as improving energy efficiency, profiling demand, maximizing utility, reducing cost and controlling emission. The authors also explored various management methods to achieve these objectives. For the smart protection system, they discussed failure protection mechanisms, which will improve the reliability of the smart grid and explored the security and privacy issues [7], [13].

Comparison in Table 1 summarizes automation of electricity utility management in terms of protocol, topology, network, hardware chips or modules and applications used for automated management of electricity. As per survey of related works, its observed that automated electricity meter reading uses GSM, GPRS, 3G, PLC and ZigBee based networks for a communication. SMS based prepaid electricity billing systems are also used [1], [14].

2.3. Water as Public Utility

Water meter should be introduced across the country to help tackle water shortages. Meters provide water use information that will help the department to monitor the effectiveness of water resource plans and their progress in meeting environmental flows and water allocation objectives. Metering water use encourages more efficient management practices, allowing a better usage of water used and improve water use efficiency. There are a number of advantages of using Supervisory Control and Data Acquisition (SCADA) in water distribution [15].

L. Cao *et al*. in 2008 presented a remote real time AMR system based on wireless sensor networks [4], where AMR sensors were implemented on water supply system. Presented mechanism employs distributed structure based on WSN, which consists of measure meters, sensor nodes, data collectors, and server. For short-range communication, RF and ZigBee are used to collect data, and CDMA cellular network is used to collect data from the server. The water meter data are received at the server through LAN using TCP/IP protocol.

M. Fayed *et al*. in 2011 proposed a flexible architectural framework for water management based on WSN and highlighted the need for water management [5]. The authors found that, WSN could play a very important role in helping to reduce water wastage, increase water efficiency and utility. Building such a WSN presents many challenges, which are different from those of other applications. In this mechanism, authors discussed and proposed an architectural framework to address those challenges. The proposed framework allows for substitution of the mechanics of transport for information, thereby increasing fault tolerance, and resiliency during natural or manmade disasters.

Y.-W. Lee *et al*. in 2008 proposed wireless digital water meter with low power consumption for AMR [16]. Authors used magnetic hole sensors to compute water consumption. The readings are transferred via ZigBee to a gateway. It is suggested that dual 3-volts batteries having 3 Ah, would last 8 years by analyzing the real power consumption.

Table 2
Automation of water utility management

No.	Research	Protocol	Topology	Network	Hardware	Application
1	RRT_AMR_WSN	ZigBee, TCP/IP	—	WSN, CDMA	ARM MPU S344B0X	Water well
2	FWN_WSN	Relay agent routing and scheduling	—	WSN, Multi-tiered hybrid network	—	Water management
3	WDWM_LPC_AMR	ZigBee	—	ZigBee	MSP430 MCU, magnetic Hall sensor, HLL	Water meter
4	LPWSSN_WQM	ZigBee	—	WSN, ZigBee	MPC82G516A, nRF24L01, PIC12F629	Water quality management

The researchers W.-Y. Chung *et al.* in 2011 proposed low power wireless sensor system for water quality monitoring. In this mechanism the MPC82G516A 8-bit microcontroller, and a nRF24L01 2.4 GHz wireless transceiver module, together with a PIC12F629 8-bit micro-controller are used to design a basic wireless node. These water quality parameters acquired from the sensor node are transmitted to the repeat node via 2.4 GHz wireless signal. The repeat node receives data and transmits to the main node [17], and then to PC by the using of RS232 interface. In addition, a wireless signal path from the sensor node to repeat node uses a single direction relaying method, thereby making the sensor node and repeat node to be in sleep mode when idle. In sleep mode, authors claim all nodes consume only 27 μA at 3 V.

2.4. SCADA Systems

Water SCADA is the term usually used to describe the computerized central control system used in many drinking water utilities. SCADA system replaced the legacy control schemes, which utilized electromechanical process control. The components were fitted with Programmable Logic Controllers (PLCs), the individual wires were replaced by Ethernet cables and the control panel was replaced by Human Machine Interface (HMI) software operating on a PC. The dedicated communications channels for remote facilities were replaced by Internet cable connections and wireless link.

The Internet SCADA system was implemented by Z. Feng *et al.* in 2008. A computer screen replaced the large mechanical control panel with its dozens of dials, levers and mechanical control. The data logger is connected to the electronic readout on pressurized systems and pressure transducer on canal systems. Basic data for water users is to collect water flow. For water users, the minimum interval for collecting data would be once weekly, although most users find that collecting at more frequent intervals.

Recent advances in communications technology and WSN made new trends to emerge in agriculture sector [13]. One such new trend is using WSNs in monitoring water level in the farm area for precision agriculture. Few algorithms offer a maximum opportunity of delivery of water level information packets or signals to base station.

2.5. SCADA Security

SCADA systems or distributed control systems are widely utilized in industries plant or infrastructure like electric or water or gas production and distribution systems. In the other words, in case of disruption or destruction of these critical services, catastrophic events might be occurred. Research has revealed that there is a lack of security in SCADA systems. Although they have historically been isolated from other computers like enterprise networks, they have been interconnecting with enterprise network or Internet by spreading with TCP/IP as a carrier protocol. This has been led to emerge new vulnerabilities while proprietary OS have been incapable of performing emerging security mechanism. Control system communication protocol like Modbus, Profibus and DNP are still used widely in control system network, even though some more secure protocol or version are developed. Existing vulnerable protocols will continue to be used in the future by reason of economy and backward compatibility. The lack of strict security policy including weak protection of user credentials cause, information leak through insecure service configuration, services running with unnecessary privileges as well as unauthorized physical access to devices. It must also ensure that only authorized parties have access to system, services and sensitive information about system structure and elements. Comprehensive strategy for cyber attacks against the nation's critical infrastructure requires understanding the nature of the threats. Therefore, it is necessary to create depth defense and proactive solutions in terms of improving the security of SCADA control systems.

Table 2 summarizes automation of water utility management in terms of protocol, topology, network, hardware and applications used for integrated automated management of water metering and control.

2.6. Gas as Public Utility

The wireless remote gas meter is a new type intelligent measurement equipment with an added function of remote

Table 3
Automation of gas utility management

No.	Research	Protocol	Topology	Network	Hardware	Application
1	AGMRS WSN	ZigBee	—	WSN, GPRS	—	Gas

control as compared to ordinary gas meter. Automation enables the gas companies not only to monitor and control the meters remotely. It also accurately counts the gap between total gas supply and gas consumption, so as to digitize and modernized management of the gas. All the diaphragm gas meters have their relative wireless remote meter product model with direct-reading technology and built-in antenna.

In view of the status and shortcomings of existing Gas meter reading systems, Y. Jie Yang *et al*. in 2012 propose an automatic gas meter reading system based on the WSN and GPRS technologies [18]. The proposed mechanism is consisting of three level network. The first and the second level use the different frequencies during communication. It decreases the interface of each other during the data translation and increase the smart gas meter lifetime. The proposed system has the advantages of easy construct, flexible layout and lower power consumption. Table 3 summarizes automation of gas utility management in terms of technology, protocol, topology, network, hardware and applications used for integrated automated management of gas metering and utility.

2.7. Communication Technologies for Utility Management

A communication technologies used in each type of utility is shown in Fig. 2. For electricity utility management, there are three types of controls such as single phase, three phase and smart grid. The communication technologies used for electricity utility management under single phase and three

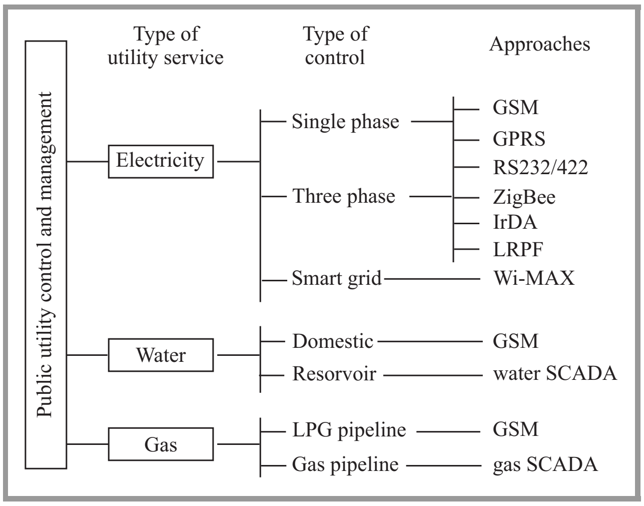

Fig. 2. Technologies used for automated public utility management.

are GSM, GPRS, RS232/422, ZigBee, IrDA and LPRF. Smart grid management uses Wi-MAX.

For water utility management, there are two types of controls such as domestic and reservoir control. For gas utility management, there are two types of controls such as LPG pipeline and gas control. The communication technologies used are GSM and gas SCADA respectively.

AMR uses various technologies and protocols for meter data collection such as PLC, Wi-Fi, ZigBee, Bluetooth, LPRF and GSM network. The taxonomy is as shown in Fig. 2. The smart meter can be used to implement the features of billing, credit management, communication, remote connection or disconnection, revenue protection, power quality measurement, load and loss control, load forecast, common user console with power management. The new designs will also support advanced tamper detection and as well support geographical information by GPS. The smart meter will have features like remote unit with display, touch screen to set different load profile options and control. AMR system helps the customer and energy service provider to access the accurate and updated data from the energy meter. AMR system can send energy consumption in hourly, monthly or on request. This data is sent to central system for billing and troubleshooting. These data are stored into the database server for processing and recording.

2.8. Comparison of Communication Technologies

There are various advantages and drawbacks in communication technologies used for utility management. Table 4 summarizes pros and cons of various technologies used in this area.

A WSN consists of densely distributed sensor nodes in a geographical area for collecting and processing data. Further transmitting the data to nearby base stations for processing. Short-range radio communication is used for transmission of data between the sensors. Transmission coverage becomes very important parameter, it measures how effectively monitored data by sensor network. The WSNs coverage issues are shown in Table 5.

Table 5
Frequency and range for AMR communication

Band [MHz]	Indoors [m]	Outdooors (with obstacles) [m]	Outdoors (with in line-sight)
433	< 100	< 500	1–2 km
800	< 50	< 300	0.8–1.5 km
900	< 30	< 200	< 800 m

Table 4
Technologies used for AMR communication

Wi-MAX (IEEE 802.16)	It does not require deployment of a costly wired infrastructure	Early stage of deployment, uncertain whether the technology will meet its range targets
Narrow band	Field-proven in Europe	Expensive deployment and not suited for particular application
Cellular service	High coverage area and potentially low costs	Fast development of new technology and their is danger of being tied to one service provider some packet-switched services not very reliable
Satellite services	Universally available, regardless of concrete location	It has high cost of maintenance, low reliability during bad weather conditions
SMS/GPRS	Low costs and highly reliable	Low bandwidth and thus only support of a few applications such as simple emergency alerts
ZigBee (IEEE 802.15.4)	Low power requirements low implementation cost with good scalability. It is particularly designed for use in industrial and home automation or security applications	It is suitable for low power requirements, it requires low implementation cost. It has good scalability. They are particularly designed for use in industrial and home automation or security applications
Bluetooth (IEEE 802.15.1)	It is more mature than ZigBee and many products already available. It permits higher data rates than ZigBee	Most meters do not have Bluetooth implementation. It has limited maximum number of devices in a network. There are issues with security vulnerabilities
Wi-Fi (IEEE 802.11)	Deployment is easy and cost is falling	Only useful within the customer site. It requires additional security layers

Cluster tree is the best topology for a large public utility control and management network. Ring and star topology are unsuitable due to their sheer scale of the entire network. Cluster tree topology allows network to divide into sub parts and they are easily manageable. A cluster tree network provides enough room for future expansion. It overcomes the limitation of star network topology, which has a limitation of hub connection points and the broadcast traffic induced limitation of a bus network topology. All nodes in cluster tree have access to their immediate network neighbors. The cluster tree network makes it possible for multiple network nodes to be connected with the central hub or data fusion.

2.9. Battery and Network Life

The reliability of a WSN is related to the availability of a communication path between two wireless devices. The sensor nodes in WSN operates on battery power. The power source for wireless sensors has mainly been disposable as primary batteries. Since networks consists thousands of sensor nodes, challenge is with using disposable batteries and maintaining sensors in service locations. Changing the batteries in the field is therefore a cumbersome task [16], [19]. Randomly distributed sensor networks makes difficulty to changing batteries. Making recharging almost impossible during operations. This problem has forced WSN and node developers to make changes in the basic architecture to minimize the energy consumption. Nodes make the network and overall system application more energy efficient.

Recently the IEEE 802.15.4 standard was developed for low data-rate application, which needed to last for longer duration by consuming relatively less energy. ZigBee 802.15.4 technology is one of a number of promising technologies for wireless communication due to its low cost and complexity, and overall energy efficiency.

Studies by Polastre *et al*. (2005), Chiasserini (2002), Kumar *et al*. (2005), mentioned that lifetime of wireless sensor networks before their installation is an important concern. Study shows, still there are some precautions to be taken by which a sensor network system can be made to run for longer time [17], [20], [21]. The problem of battery energy consumption in sensor networks depends on node architecture, network structure and routing algorithm to support energy saving in the network. Stand-alone measures such as selecting a low-power microcontroller with embedded transceiver will important factor to achieve energy saving over the entire network. Energy efficient WSN design objectives needs to look at different aspects, such as application code, network configuration, routing algorithms, etc.

Numerous types of batteries are available including alkaline, carbon zinc, zinc air, and lithium based batteries. Traditional energy harvesting such as solar, piezo, and thermal, share a common limitation of being reliant on ambient sources generally beyond their control. Hence, these solutions are not suitable for WSN. The majority of researches use a definition suitable for the context of their work [10].

The novel AMR devices generate high current pulses at periodic intervals with little current between signal transmissions. Lithium thionyl chloride batteries are generally preferred to power AMR devices due to their inherent long life and high-energy density. Among of all the available lithium battery chemistries, bobbin-type Li-$SOCl_2$ cells offer the advantages of higher energy density and voltage, excellent temperature characteristics, low self-discharge rates and good safety. Many of these components have been operating for over 15 years without a battery change. Study shows that these batteries can last up to 20 years. Reliability is another major advantage, as these batteries can operate in severe environmental conditions from –40 to 85°C.

3. Integrated Solutions for Utility Management

Apart from the wide variety of individual electricity or water or gas or automated public utility management solutions discussed in previous sections, there are many integrated automated public utility management services, which fit into more than one category. In this section all such solutions proposed by research community across globe in this domain have been briefly described.

The author Aghaei in 2011 proposed WSN in water, electricity and gas industry in which sensors compose main components [22]. Sensors are deployed and are connected with each other in environment dynamically. In this mechanism, it is presented a model for processes which are related to user of water, electricity and gas meter reading. Distribution of bills, sending notice, cutting, and reconnection of flow by using WSN were tested in Iran. The researcher showed that the proposed model leads to a great deal of costs savings.

Garlapati *et al.* in 2012 proposed a hybrid spread spectrum based smart meter network design that reduces the overhead, latency and power consumption in data transfer when compared to the 3G cellular technologies [23].

ZhiliZhou *et al.* in 2013 proposed an optimal relay node placement in WSN for smart buildings metering and control. This mechanism examines WSN communication infrastructure for smart grid implementation in building. Proposed a scheme for the deployment in buildings, in which sensors are massively placed to meter electricity consumption and collect illumination, thermal, pressure information and multiple base stations are connected with the communication network for power grid distribution network [24]. The paper exploits the software tool to simulate building environment and to test optimal deployed WSN. Integer programming approaches for both deterministic and robust cases are considered.

Das *et al.* in 2012 proposed cost optimization of wireless-enabled AMI, which measures, collects and analyzes information by communicating with metering devices either on request or on a schedule. The AMI consists of a collection of Neighborhood Area Networks (NANs), which include smart, wireless-enabled mesh-connected meters or sensor nodes. Each NAN is controlled by a gateway or Access Point (AP). These devices in turn are usually mesh-connected using wireless or wire-line backhaul links to a servers. This contribution develops an elegant graph-theoretic approach for optimizing the cost of an AMI by maximizing the ratio of the number of sensors nodes in a NAN to that of gateways or APs. A Matlab program has been implemented to automate their approach, which can deal with random and complex NAN topologies.

Cao *et al.* proposed in 2009 remote wireless AMR system based on wireless mesh networks and SOPC technology [14]. The system consists of measure meters, wireless sensor nodes, data collector, management centre and wireless communication networks. The data is transmitted from the sensor nodes to the data collector using ZigBee. The system uses Ethernet to transmit data from the data collector to the management centre. The data collector acts as gateway, it is adopted wireless mesh network topology structures. Management center is based on FPGA chip. In ZigBee sensor node design, Atmel MEGA128 microcontroller is used. Wireless chip TI CC2420 is used for communication unit. The systems presented in this mechanism have many significant excellences, such as networked, wireless, moveable and lower power consuming. The proposed system have abroad application foreground in the real application field to remote measure and manage of electric power, water supply, gas supply and heat supply.

Di Zenobio *et al.* in 2012 carried research on self powered wireless sensors. Described mechanism is a new solution for a wireless self-powered sensors network, which allows the energy harvesting from the action of a turbine wheel rotating in the path of a fluid stream environment [25].

New devices family was introduced to find application in water or gas smart metering systems. Reinhardt *et al.* in 2011 and Cao *et al.* in 2008 presented low-power hardware mechanism and incorporates it in a reprogrammable microcontroller, which allows developers easily deploying new algorithms. This IEEE 802.15.4-compliant radio transceiver makes its integration with existing sensor [3], [25], [26].

Francisco *et al.* in 2013 proposed automated meter reading and SCADA application for WSN. The authors found that currently, there are many technologies available to automate public utilities services [13]. AMR and SCADA are the main functions these technologies must support. In their work, authors propose a low cost network with a similar architecture to a static ad-hoc sensor network based on low power and unlicensed band radio. Topological parameters for this network are analyzed to obtain optimal performance and to derive a pseudo-range criterion to create an application-specific spanning tree for polling optimization purposes. In application layer services, authors analytically studied different polling schemes.

Table 6 summarizes automation of utility management in terms of various technologies, protocol, topology, network, hardware and applications used for integrated automated management of utilities.

This research study shows that, there is scope to integrate multiple utility sensors using common platform. The proposed hardware are SoC based on FPGA using ZigBee tech-

Table 6
Automation of integrated utility management

No.	Research area	Protocol	Topology	Network	Hardware	Application
1	WSN_WEG	Semiautomatic WASN, SMS	—	GPS, WSN	—	Water, gas, electricity
2	HSS_SM	HSS, multiuser detection	—	HSS based AMI network	PIC MCU	Electricity
3	ORNP_WSN_SBMC	DRP_IS, RNP_IS	—	WSN, ZigBee	—	Electricity, thermal, pressure
4	CO_WSNBI	—	—	WSN	—	Electricity
5	AMR_WMN_SOPC	ZigBee, TCP/IP, CSMA/CD	Mesh network	ZigBee, IP	FPGA, EP2C35F67272C8, MCU, MEGA128, CC2420	Water, gas, electricity
6	SP_WS_WGMS	M_Bus	—	UMTS, LTE, 3G	MSP430L092 MCU	Water, gas
7	AMR_SCADA_WSN	Spanning tree	Static ad-hoc sensor network	WSN	—	Water, SCADA

nology. The Hybrid Spread Spectrum (HSS), ad-hoc, mesh and NAN topologies are found to be suitable for utility management and water SCADA.

In fact, the actual selection of utility technology depends on several factors such as geographic coverage of the communication architecture, the locations of substations, cost of communication architecture, and a remote control center with network management types. As a result, electric utilities should evaluate their unique communication requirements and the capabilities oftechnologies comprehensively in order to determine the best solution for automation applications [20], [27].

4. Issues and Challenges in Automated Control and Management of Public Utilities

Global metering service industry is a heterogeneous one with multiple communication protocols and interfaces. Another issue is the difficulties in integration of different make of meters at the field level. Evolution of the electricity has historically taken place with proprietary protocols and interfaces to provide internally stored values in formats is unique to the manufacturer. With the change in requirements of the utilities, additional parameters and features have been added resulting in different versions of meters even from the same manufacturer. The users and service providers with these multiple versions of meters are burdened with multiple data formats on proprietary protocols. The utilities service providers have to buy and maintain separate Application Program Interface (API) software from each meter manufacturer in order to make use of the data from different versions. In addition, third party hand held readers and remote metering systems have to be updated for every new meter type or version. The proprietary protocols results in dependence on the vendors of meters as the APIs are needed for integration of metering information with the IT infrastructure. This resulted in focus on the development of open integrated utility metering protocol and interface.

The interoperability is the capability of the data collection system to exchange data with meters of different makes. This necessitates the presentation of the meter data in predefined common formats and interface. This calls for the meters which results in compact, low cost and efficient programming effort for applications using IT infrastructure. The evolution of enhanced capabilities of microprocessor based meters and the benefits led to development of open protocols independent of make. With the availability of open protocols, many options and features become available to the purchaser or software developer who may want to take advantage of them to optimize their operations or to maximize their commercial benefit.

Battery life is a critical issue for communicating AMR meters. The communicating AMR meters rely on batteries. There is a need to obtain the longest possible period of performance battery.

5. Future Research Directions

Despite the extensive research in AMR technologies, there are still several open research issues, i.e., efficient resource and route management mechanisms, inter domain network management, that need to be developed for automation applications. Possible the research scope are:

1. network topology design and development for public utilities control and management,
2. design and development of single integrated electric, water and gas meters for efficient control and management,

3. protocol design and development using analytical and probabilistic models of spectrum management,
4. design and development of utilities database management, analysis and control using software,
5. security issue analysis, tamper proof and protection,
6. development of WSN test-bed for testing public utilities management and control protocols,
7. verification of designed meters, network topologies, communication protocols and database management using developed test-bed for improvement of energy efficiency, latency, throughput, network lifetime using spectrum management and reducing control overhead for automated public utilities management using WSNs.

5.1. Overview of Proposed Methodology

In this paper the various research for automated management of utilities have been explored. The authors believe that cluster-based routing with new protocol are good candidates that can benefit integrated automation of utility services.
The utility industry is aggressively growing towards automation by cutting operating cost and increased efficiency. To meet next generation utility management network, a new architecture for integrated automation of metering, control and management of public utilities for effective management and control of resources using wireless sensor network is proposed. For conducted research an electrical, water and gas utilities are considered. This three types sensors can be integrated into single node called as EWGSN (i.e. electrical, water and gas sensor node). The EWGSN does preliminary collection of data from three utility sensors and stores into single node. Hence, EWGSN node is considered as level one data aggregation and fusion (L1DA),

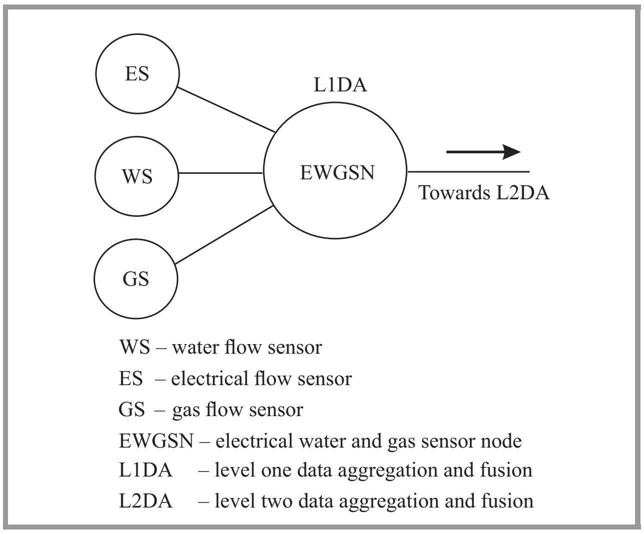

Fig. 3. Integrated sensors based AMR.

which is PAN coordinator with FFD functionality as shown in Fig. 3. The L1DA function is preliminary packetizing of sensor data into standard frame and transmits to level two data aggregation and fusion center (L2DAC). Transmit frame is used to transmit data readings from sensors at EWGSN node to data fusion centre. EWGSN Control-T consists of special requests to data aggregation centre at L2DA data fusion centre. Field check error is performed on payload using CRC 32 algorithm. Receive frame at EWGSN is used to transmit control commands data from L2DA data fusion centre to EWGSN. This frame is used for configuration to be done in EWGSN nodes remotely from L2DA. EWGSN ControlR consists of special requests from data aggregation centre at L1DA to sensors.
The proposed system are energy efficient, sensor node communicates with fusion centre on event based and nodes are always in listening mode. The single packet carries three type of payload. Since, sensor nodes are placed in utility houses rechargeable battery can be used.
The WSN based integrated control and management system mainly performs the following functions: data acquisitions, data communication, information and data presentation, monitoring and control.

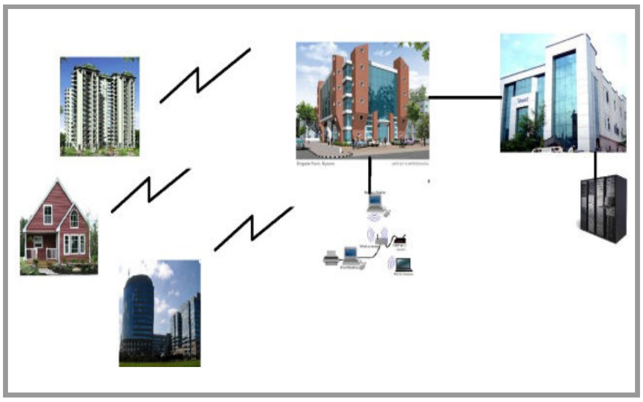

Fig. 4. Integrated AMR.

Integrated WSN based metering consist of users, i.e., individual home, apartments, offices and industries, which ware connected to nodal office as shown in Fig. 4. Nodal office is a area wise a office it communicates to users RTU in particular area through exchange of information. It is also connected to central metering and data control office. All nodal offices are connected to central office through Internet cloud using IoT as shown in Fig. 5. The central office maintains database and control part of SCADA system. The main aim of deploying the WSNs based automated utility services is to make the real time decision which has been proved to be very challenging due to the highly utility service resource constrained and communicating capacities. Huge volume of data generated by WSN based AMR sensor nodes, motivates the research community to explore novel data mining techniques, and dealing with extracting knowledge from large continuous arriving data from WSN based integrated AMR sensor node.

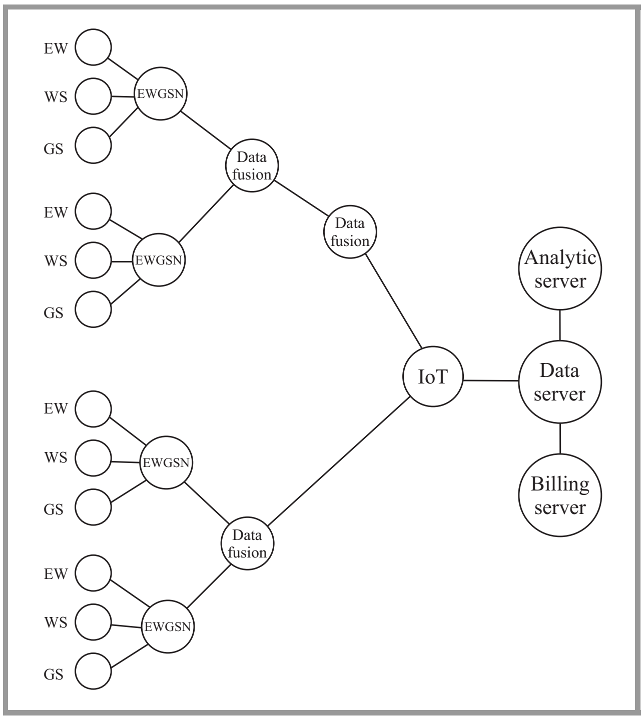

Fig. 5. Integrated sensors based AMR management.

Proposed system has following benefits:

- control units can integrate wide range of data in single frame,
- it provides on board mathematical and graphical information,
- it has ability to measure and store the historical information,
- it is easily expandable,
- to handle multiple daily data transmissions, it uses Tadiran PulsesPlus hybrid lithium battery.

6. Conclusion

Currently, there are many technologies available for automated management and control of public utilities services. There are various types of design, protocol, communication technologies and interfaces. In this paper, authors studied different methodologies proposed by various researches for automated reading and control. It is observed that WSN based solutions are cost effective for automation of integrated utility services. The conducted comparative analysis shows that automation of integrated solution with single window management of utilities appears to be highly challenging. There is further research scope for building standard frame formats, interfaces, network topology, database management, billing and network security requirement for integrated public utility management and control.

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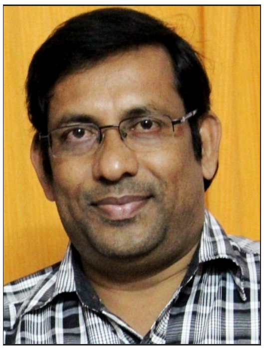

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