

A USN based Automatic Waste Collection System

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Abstract—This paper presents a novel approach to collect municipal solid waste in residential and commercial buildings using ubiquitous sensors network (USN). This technology offers exhilarating opportunities to eliminate web of wires while increasing connectivity of devices and easy expansion of network. Specifically, this research evaluates the potential of ZigBee for addressing the problem of MSW collection. The architecture of USN based Automatic waste collection system (AWCS) is proposed in this article. The proposed system is based on a series of experiments in real time scenario. The system consists of integrating wireless networks, gateways, and specially designed software. The implementation covered all processes of waste collection i.e. garbage loading and transport of waste in underground pipes from deposit spot to collection station. As compared with the conventional wired network, the proposed hybrid AWCS offers in-time fast waste collection, low installation, operational and maintenance cost along with the improvement in scalability and reliability. In short, the USN based AWCS is a high reliable and low cost real time alternate to the conventional wired-network based AWCS. To reveal the feasibility and applicability of the proposed system, sensors, actuators, and ZigBee modules have been developed and tested in real time scenario at Seoul city.

Keywords—Municipal Waste Vacuum Collection System, In-pipe communication, Ubiquitous Sensors Network (USN), Wireless Sensors Network (WSN), ZigBee

I. INTRODUCTION

Today, along with the economic growth, industrial revolution, increasing population, and saturation of urban areas, management of municipal solid waste (MSW) has become a challenging issue. The environmental impact caused by municipal solid waste has received special social and environmental attention in recent decades; especially in big cities of developing countries [1]. Further, a substantial amount of the total expenditure (85%) is spent on waste collection and transportation and as such improvement in the design of the collection systems could result in substantial savings [1]. To solve MSW collection problem, using latest technology, while ensuring green environment and sustainable development of society, is need of the day. Deploying wireless technologies for MSW collection offers a number of benefits along with efficient and environmental friendly automation approach.

Centralsug (current Envac) installed the world's first ever

automatic pneumatic refuse collection system at Solleftea hospital, Sweden in 1961, while the first vacuum system for household waste was installed in residential district of Or-Hallonbergen, in 1965 [2]. These systems are still in operation today with many original parts from the early 1960s [2]. Since then, significant research has been conducted in the field of waste management, waste monitoring, waste to energy conversion, and land filling [3]-[6]. However, very little of research worth is tackled, specifically, in the field of waste collection after it started approximately fifty years before.

Recently, wireless sensor networks (WSN) have been deployed in various applications aiming to eliminate the web of wires. In the past decade a robust upsurge is observed in adopting ZigBee standard in home automation, building automation, health care and smart energy applications [7]-[9]. It is anticipated that WSN solution leads to significant benefits in reducing cost, providing an open standard network architecture that will be scalable and reduce weight. The motivation of this work is to reduce initial cost of Automatic Waste collection System (AWCS) by suggesting wireless network based technologies in the project. This research work highlights the significant benefits of open standard network, ZigBee, in waste collection system.

Rest of the paper is organized as follows. Section 2 describes the conventional architecture of the AWCS system. Experimental results and groundwork for the proposed design is discussed in section 3. In view of results, architectural design of the USN based AWCS system is proposed in section 4. Finally, concluding remarks are given in section 5

II. CONVENTIONAL AWCS SYSTEM

A pneumatic AWCS is a waste-conveying system that transports municipal and/or household waste at high speeds via reticulated pipes to a central station [10]-[12]. Generally, the system consists of vertical and horizontal pipelines along with a set of sensors and actuating valves interfaced with three networks; Loading network (L-NWK), Transport network (T-NWK), and Collecting network (C-NWK) as shown in Fig.1.

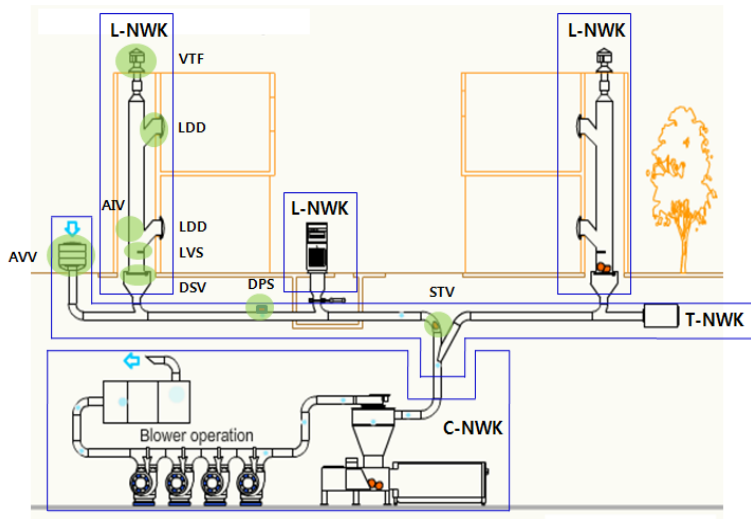


Fig.1. Pneumatic AWCS System.

L-NWK is installed at vertical pipe for garbage loading. This network consists of several SA nodes like ventilation fan (VTF), garbage loading door (LDD), air in-take valve (AIV), level sensor (LVS), and discharge valve (DSV). VTF node controls the operation of ventilation fan. LDD node controls garbage loading process. LVS keeps a check on the garbage level at temporary storage while DSV controls garbage transportation from temporary storage. T-NWK is installed at underground horizontal pipes for transporting garbage from user territory to the collection depot. This network manages Air Valve (AVV), Differential Pressure Sensor (DPS), and Section Valve (STV) nodes inside the horizontal pipe. AVV regulates the air flow in garbage transportation process. DPS checks air pressure inside the horizontal pipe while STV opts for corresponding section to fetch garbage. C-NWK is deployed at waste collection station. This network plays its role in collecting garbage at depot, indicating the garbage storage tanks, carrying trucks positions and handling the vacuum unit. Hence, vacuum unit, air blowers, and waste storage tanks are parts of this network

Finally, the control room is equipped with manage and control software (named man machine interface system (MMIS) in our design) tool to operate and sustain the system. The conventional system had been implemented by wired networks and proprietary protocols. Fig. 2 shows system architecture of the traditional design. Each individual SA is interfaced with a local controller (LC) forming a node, and finally connected to the local network controller (LNC). All LNCs are in turn connected with the main network controller (MNC). MNC is directly connected with the controlling software MMIS. Although the existing wired network based AWCS ensure reliability and green environment, it has been adopted by the residential customers in a very limited number. We analyzed the main reasons that limit installation of the existing AWCS as follows.

Expensive installation: The main obstacle to adopt the system is its high capital cost.

Exclusive Technology and Physical Wiring: The existing network based AWCS uses a proprietary network protocols for control and management of the system that require physical wiring.

High maintenance cost: In wired systems, if power failure or power disconnection problem occur, first it's very hard to point out the fault location. Secondly, it's not only very difficult to fix the problem but also it requires high maintenance cost and labor as well. Moreover, the existing systems are not intelligent enough to inform the system manager about the fault location and network failure.

Unrealistic network expansion: Wired based systems are not only hard to install but also cannot be expanded easily once installed. Moreover, for system expansion i.e. adding new customer to the system will cause complete wear and tear in the system

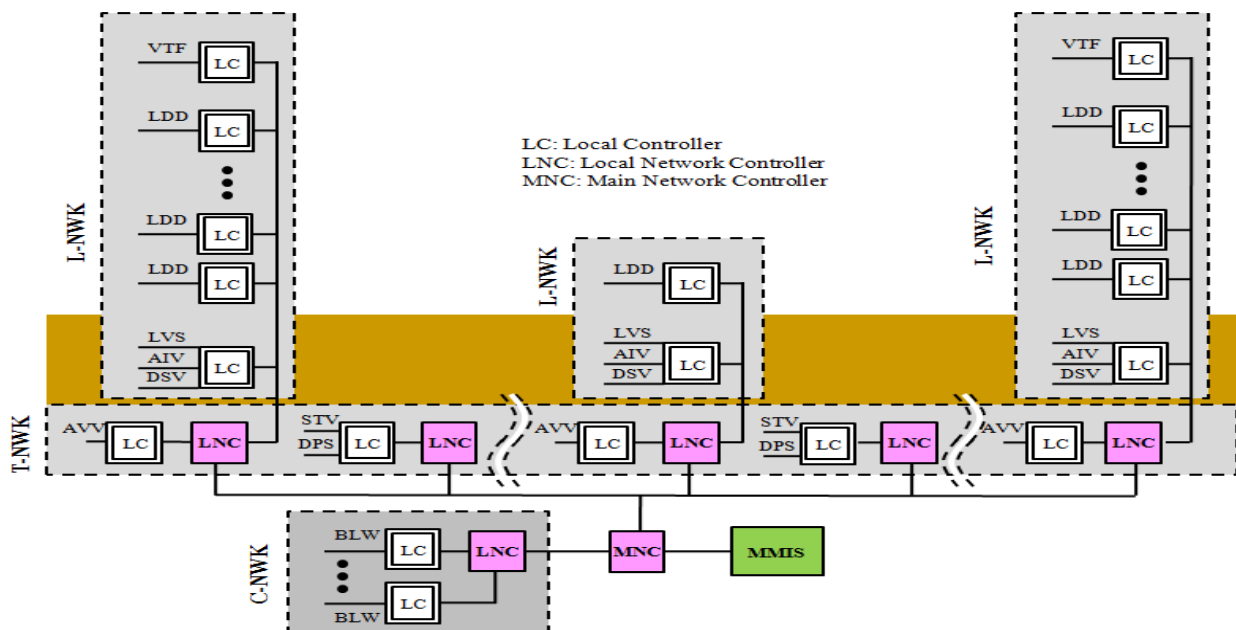


Fig.2. Conventional AWCS network Architecture.

III. GROUNDWORK

The foundation for the wireless AWCS is drawn by the significance of open standard ZigBee mesh networking and evaluating the performance of ZigBee communication inside the garbage loading and transportation pipes. Based on these experimental results, some implications for system design are addressed. To demonstrate the feasibility and effectiveness of the proposed technology in the system, nodes for L-NWK, T-NWK, and C-NWK were developed and tested in existing conventional AWCS system in high-rise residential apartments at Seoul city.

A. ZigBee mesh networking

The purpose of this research is to replace the web of wires in AWCS with ZigBee mesh networking, while ensuring reliability, interoperability, and scalability. The ZigBee standard builds on top of the MAC and PHY layers of the IEEE 802.15.4 and provides a complete network stack for wireless SA networking. There are two categories of devices in the IEEE 802.15.4: Full Function Devices (FFDs) and Reduced Function Devices (RFDs). An FFD device can take two different roles in a ZigBee network: Coordinator (ZC) and Router (ZR). The ZC is capable of forming a ZigBee network and unique within the network. The ZR has the same routing capabilities as the ZC, but can only join a network, never form it. An RFD device, called End Device (ZED), can only join a network and has no routing capability. There are two network topologies specified in IEEE 802.15.4: star and peer-to-peer. In the star topology every ZED can communicate only with ZC in its radio coverage region. In a peer-to-peer (or known as mesh) topology each ZR can communicate directly with any other ZR if devices are placed close enough together to establish a successful communication link. However, ZED can be part of the network and communicate only with one particular ZR or ZC in the network. [13].

B. In-pipe communication

This article suggests wireless communication inside pipe for the project. Pipe channel acting as a waveguide is a time-invariant and electrically shielded from the outside. The path loss in pipe is lower compared with a coaxial cable and with free-space propagation. Various transmitting powers or frequencies can potentially be used inside pipe without violating interference regulations. The waveguide cross-section shape and size define a cutoff frequency below which signals cannot propagate inside the waveguide. Table 1 gives cutoff dimensions for rectangular waveguide of wide dimension a and circular waveguide of diameter D [14]. These dimensions define the minimum cross-section size that is required to carry different UHF signals. As one can see, standard circular AWCS pipe that have diameters on the order of 30~60cm can easily be served as waveguides for AWCSs operating above 900 MHz.

Table 1: Cutoff dimensions for waveguides

Waveguide	Minimum dimension	900MHz	2.4GHz
Rectangular	$a_{\min}=c/2f$	16.7cm	6.3cm
Circular	$D_{\min}=1.841c/\pi f$	19.5cm	7.3cm

C. Preliminary Experimental Results and Discussion

Extensive experiments were carried out to check the performance of ZigBee communication inside the L-NWK and T-NWK for different scenarios. In our experiments we have used Ember EM357 integrated ZigBee Radio Control Module (RCM) [13] as our SA nodes shown in Fig.3

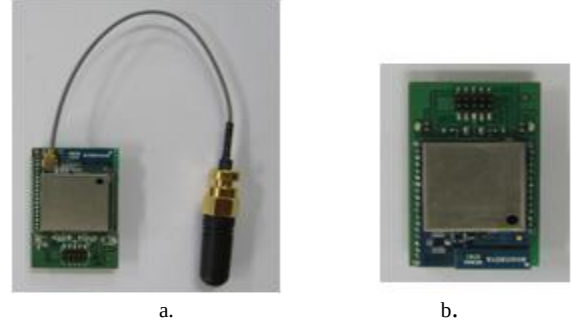


Fig.3. ZigBee RCM with: a) SMA antenna. b) SMD antenna
1) L-NWK

Fig.4 shows experimental setup for L-NWK. ZigBee communication was tested for two different situations. In each experiment, ZC is placed inside the vertical pipe at first floor. At first, ZED is placed in the vertical pipe inside the bin door at 32nd floor while for the second case its position is changed to 64th floor of the building.



Fig.4. ZigBee communication testing in L-NWK.

RSSI was measured by the Ember Insight Desktop for both cases.. The experimental distance between ZC and ZED is 112m and 224m for 32nd floor and 64th floor respectively and the average value of RSSI and variance in dBm are measured for both the cases and results are given in table 2.

Table 2. Results for L-NWK experiments.

SMD Antenna	32 nd floor (112m)	64 th floor (224m)
Average RSSI	-29.8dBm	-60.93dBm
Variance	0.16	0.06

2) T-NWK:

For T-NWK, two sets of experiments were conducted.

Stainless horizontal pipe:

In first set, experiments were conducted in stainless shiny inner surfaced horizontal pipe. Firstly, ZigBee communication is tested in pipe full of garbage and then it is investigated for empty pipe. For both cases distance between ZC and ZED was kept constant at 240m. Pipe full of garbage means that communication channel is blocked by the garbage as shown in Fig. 5a while empty pipe depicts that communication channel is free having no blockage as shown in Fig. 5b. The RSSI and variance were and results are tabulated in table 3.



Fig.5. ZigBee communication testing in T-NWK stainless shiny horizontal pipe. a) Pipe full of garbage. b) Pipe without garbage.

Table 3. Communication results for T-NWK stainless horizontal pipe.

SMD Antenna	Empty pipe (without blockage)	Pipe full of garbage (blocked)
Average RSSI	-24.7dBm	-36.97dBm
Variance	0.41	0.03

Stained horizontal pipe:

In second set, the experiments were repeated for stained inner surfaced horizontal pipe as shown in Fig.6. During experiment, position of the ZC was fixed and that of the ZED was changed to four different positions i.e. 80m, 120m, 180m, and 240m. At first, the experiment was conducted with SMD antenna. Secondly, the experiments were repeated for SMA antenna with gain. The results are accumulated in table 4.



Fig.6. ZigBee communication testing in T-NWK stained horizontal pipe.

Table 4: Communication results for T-NWK stained horizontal pipe experiments.

*NC: No Communication.

Antenna		Position1 (80m)	Position2 (120m)	Position3(240m)
SMD		NC	NC	NC
SMA	1dBi	NC	NC	NC
	3dBi	ok	50%	NC
	5dBi	ok	ok	50%

The results indicate that ZigBee is a reliable and promising technology for L-NWK of the AWCS system. The radio specification shows 1% of packet error rate (PER) for 20 byte packet size at -100dBm normal RX sensitivity. In our experiment, up to -60dBm of RSSI, no packet transmission error occurs. Based on data sheet [13] and experimental results, 30 dBm margin can provide further coverage. However, the RSSI results for T-NWK were not satisfactory and illustrate limitation of the technology in stained horizontal curved pipe. Here the conventional wired network can be installed. However, polished shiny horizontal pipe allows the ZigBee communication. Hence this technology can be deployed in that portion of horizontal pipe where there is only air transportation.

IV. PROPOSED SYSTEM

Based on experimental results, a hybrid AWCS design is proposed in this section.

Architecture

Technological architecture of the system consists of one MMIS, gateways, and three networks i.e. L-NWK, T-NWK, and C-NWK as shown in Fig. 7. Each L-NWK makes a WPAN network inside vertical pipe and is connected to the T-NWK through ZC-ZR serial bridge. On the contrary, all the T-NWK LNCs are connected with MNC via conventional wired network. The MNC is in turn wired connected with the control room via MMIS. Hence the hybrid AWCS system fixes the horizontal pipe communication problem through conventional wired network based technique.

MMIS:

MMIS is a specially designed software tool, installed in laptop/PC, to watch over and manage the system intelligently. It is a virtual environment where the actions demanded by the users are checked. It is responsible for the administration of security and authenticity of the users in the AWCS system. It is a source to commission the users and debug any fault occurrence in the communication networks of the system. Moreover, MMIS is the network initiator. It starts the system

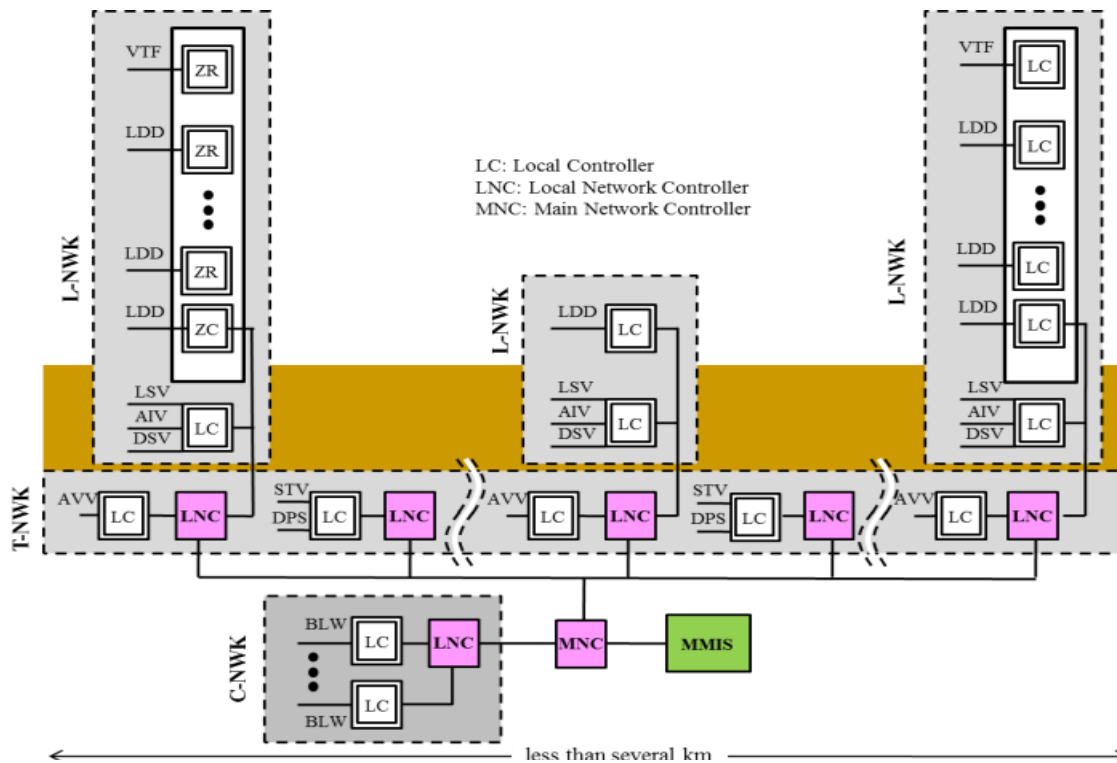


Fig.7. Hybrid AWCS architecture

and checks it on regular basis. MMIS allows the system to update and expand along with the central controlling mechanism. Furthermore, any node failure or any fault occurrence in the network architecture of the system is reported to MMIS. The primary function of this tool is to provide safety, security, and central command in the system

Gateways:

A PC-to-ZigBee (specifically MMIS-to-ZigBee) gateway is designed to provide interoperability between MMIS and ZigBee networks. This gateway facilitates the control room to establish a communication channel between supervisor and all three ZigBee-based WPAN networks. The primary service offered by the gateway for the proposed architecture is that it provides an interface between the supervisor and the whole system offering him a complete access and allowing him to configure and manage the system. Secondly, it provides data translation from MMIS format to ZigBee format and vice versa. Also another gateway (ZC/GW1) is designed providing connection and protocol translation between ZigBee and wire-line backbone network such as Internet or PLC.

Networks:

The proposed AWCS system comprises of same network s as in conventional system with additional B-NWK. All networks are connected with MMIS through wired or wireless network.

i.L-NWK:

L-NWK is garbage depositing spot. Wireless SA nodes are mounted inside the vertical pipeline making a ZigBee WPAN. Private LDD nodes in L-NWK form a WPAN using in-pipe communication. L-NWK is connected to the T-NWK through ZC-ZR bridge. In addition to LDD nodes, L-NWK includes WPAN SA nodes such as LSV, AIV, and DSV located at basement. The LCs controlling these SAs are connected with nearest ZRs at first floor.

ii.T-NWK:

T-NWK is deployed in underground horizontal transportation pipeline. AVV SA node of this network is usually located near to DSV of L-NWK. Hence this node is linked to L-NWK. STV and DPS SA nodes are generally installed at the vicinity of branch of transportation pipe. They are installed at the manhole for easy access. STV and DPS are deployed as in conventional system.

V. CONCLUSION & FUTURE WORK

In this paper we have presented a smart and novel pneumatic waste collection system based on USN technology, ZigBee. This research is characterized by some attractive and innovative features for example; in-pipe communication is suggested for SAs contact in the AWCS system. It is shown in the results that vertical pipe in the system provides a safe

communication medium avoiding interference with other wireless technologies. However the horizontal stained pipe results doesn't allow radio communication. Concerning the communication failure in the horizontal pipe, although alternate method is proposed, yet we will come up with completely wireless solution in near future. Overall, the results suggest that ZigBee is promising technology for implementing L-NWK of AWCS while practical problems, such as interference, noise and environmental conditions, may occur by deploying ZigBee in T-NWK of the system. Moreover, the architecture is designed to reduce system complexity providing central control mechanism, user friendly interface, and easy operation. Furthermore, the use of ZigBee communication lowers the capital as well as maintenance cost of the system by eliminating the web of wires. Wireless mesh networking of ZigBee increases reliability providing robustness and flexible expansion to the system. Hence, the successful use of ZigBee in the system helps to retrofit from conventional AWCS systems as it requires only nodes installation.

The project is in progress and we are looking for alternate methods to make it completely wireless. We are designing other gateways that will provide connection and protocol translation between ZigBee and other wireless networks such as Wi-Fi, WiMAX, and WCDMA. Also we have designed a test-bed system and are working on the circuit design and implementation of the project in residential apartments at Seoul.

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