fNode : Reducing Network Packet Transmission Overhead in Indoor Heterogeneous Wireless Sensor Networks

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Abstract of Bachelor's Thesis

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Wireless sensor networks (WSNs) have become popular because of the availability of a variety of sensor node hardware, each having its own unique capability. However, combining several sensor node platforms for a certain wireless sensor network application meets many difficulties such as the differences in radio frequency, network protocols and system architectures. Such WSNs are often referred to as a heterogeneous WSN.

This thesis describes the improvement of performance of a heterogeneous WSN deployed in indoor building environment under common sensor networking architectures by reducing the total packet transmission occurring. Our approach is to combine the existing WSN infrastructure with fNode, our implementation of a sensor node capable of forwarding packets of different communication architecture, which is used to replace the redundant nodes within the network. We have implemented and evaluated our work under a real-life indoor environment using 15 sensor nodes. Our experimental results show that fNode reduces the total packet transmission overhead, power consumption and latency within the WSN by approximately 30%.

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fNode：通信中継ノードによるヘテロジニアスセンサネットワークの効率化

近年無線センサネットワークに関する研究が盛んに行われている。センサネットワークを構成するセンサノードは多種多様であり、それぞれ異なるハードウェア基盤、通信メカニズムによって構築されている。これらの異なるセンサノードによって構築されるセンサネットワークをヘテロジニアスセンサネットワークと呼び、多様なセンシングアプリケーションを実現することが可能である。その反面、ヘテロジニアスセンサネットワークにはハードウェアとソフトウェアの非互換性による様々な課題が存在する。例えば、異なる種類のセンサノード間では、ノードに実装されている通信チップやパケットの形式が異なるため直接無線通信を行うことはできない。

本論文では、ヘテロジニアスセンサネットワークにおける通信の効率性、省電力性、そして信頼性を高めるために、異なる通信基盤を持つセンサノード同士の通信を可能にするためのセンサノード、fNode の提案を行う。fNode は異なる通信基盤を持つセンサノードの間の中継ノードとして作用し、センサネットワーク内の冗長なセンサノード群を fNode によって置換することで異なる種類のセンサネットノード間の通信を可能とすると共に通信の効率性および省電力性を達成する。本論文では fNode の実装を PC 上に行い，実環境において 2 種類のセンサノードから構成されるセンサネットワークにて評価を行った。評価の結果、fNode を用いることにより、センサネットワークの総パケット通信量、電力消費、ネットワーク遅延をそれぞれ 30%- 35%削減することに成功した。

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Chapter 1

Introduction

1.1 Motivation

Wireless sensor network (WSN) is an active field with numerous significant breakthroughs in technologies and researches each year. With the advancements of wireless, energy, manufacturing, and several other technologies, sensors are applied to many feasible applications such as building management [9] and weather monitoring [11] sensor networks.

Heterogeneous wireless sensor network (HWSN) consists of sensor nodes with different capabilities such as various sensor hardware platforms, radio frequency and sensing range, thus provides more flexibility in sensing and deploying. For example, a building monitoring WSN consists of multiple kinds of sensor nodes to provide various sensing services such as fire sensing, ambience sensing, sound and temperature sensing. In the previous case, two types of nodes could co-exist in the same geographical region; one have a long communication and sensing range, while the other with limited and shorter sensing capability. Under this case, an effective deployment method of these mixed nodes achieves a balance of performance and cost of the sensing task as a whole network. For example, some sink nodes are equipped to reduce network packet transmission of nodes having short communication range, thereby reduce the power consumption and latency of WSN. Researchers have been proposing advantageous ways of packet transmission and deployment to deal with the power saving, real-time and deployment problems of heterogeneous WSNs.

1.2 Challenges and Goal

As a solution to the aforementioned problems, sink nodes could be added to the network in order to increase the network's quality, by reducing the total packet transmission overhead within the network. Besides, there are many research works to propose deployment topologies [7]. However, if multiple sensor nodes with limited communication capability are to be set up in a distant location from the sink node, multiple hops of data forwarding is required to transmit the packets, which results in expensive and inefficient data transmission.

In this thesis, we propose fNode a sensor node capable of forwarding packets among different sensor platforms and fMap a tool for selecting the ideal deployment position of fNode within the sensor network.

1.3 Structure of Thesis

The rest of this thesis is organized as follows. In Chapter 2, we briefly present related work on heterogeneous WNSs. Chapter 3 describes the features of heterogeneous WSNs and introduces packet transmission problems in Chapter 4. We continue with our solution in Chapter 5 by proposing fNode, fMap and explaining their features. We then state the design and implementation of fNode and fMap in Chapter 6. Chapter 7 provides the experiments and the performance of fNode and fMap under various scenarios. Finally, in Chapter 8, we conclude this thesis and introduce our future work.

Chapter 2

Related Work

2.1 Introduction

In this chapter, we introduce and summarize related researches which solve packet transmission, power saving, real-time and deployment issues of sensor networks.

2.2 Network packet transmission

Leogrande [1] introduces a new application framework for flexible packet processing in heterogeneous sensor networks abstracted by an XM-based language. The framework helps perform tasks effectively such as packet dissecting, defining, processing and filtering in the back-end applications. The framework is designed with characteristics of modularity, symmetry and I/O management capability. In order to demonstrate the advantages listed above, three WSNs applications of the proposed framework are presented: a simple WSN packet sniffer, RSSI-based localization of mobile WSN nodes, heterogeneous light and temperature network. The advantages of this approach is an increase in flexibility, adaptability and extensibility of applications. However, this approach only focuses on processing messages, so the problem with packet transmission overhead is still unsolved.

Mobile sinks in WSN (MSSNs) [24] is a WSN where a mobile sink is responsible for gathering the data packets from the sensor nodes with similar observations. The idea of

WSNs with mobile sinks is a effective solution to take advantage of short-range transmission while it can exploiting the simplicity of single-hop transmission. The transmission scheduling has attracted much attention as the challenging issue in MSSNs. In [23], Sharifkhani proposes a transmission scheduling algorithm based on the well-known tradeoff between the probability of successful packet arrival at the sink node and the energy consumption, when a single transmission channel is required at each time slot on the sensor nodes. However, using mobile nodes can make delay time longer.

2.3 Power saving and Real-time

Lifetime of deployed sensor nodes is a key issue in WSNs. Therefore, minimizing energy consumed by sensing and communicating is an important design objective. Qiu [2] proposes an adaptive online energy saving (AOES) algorithm to reduce the total energy consumption of heterogeneous WSNs. The basic idea is to use a time interval and obtain the best mode assignment of each node in that time interval. Then the mode of each node is adjusted accordingly online. However, the availability of WSNs is decreased.

PER [3], a power saving hierarchical routing protocol, is proposed for heterogeneous sensor network (SN), optimized via cross-layer designs to save sensor's power. Edison [4] proposes to address the real-time concerns in HWSNs by using the Object Management Group Data Distribution Service for Real-time Systems approach.

2.4 Deployment and Topology control in Heterogeneous WSNs

Topology Control Based on Irregular Sensor Model [7] proposes a heterogeneous WSN deployment method based on irregular sensor model developed from the radio propagation model inspired from Radio Irregularity Model (RIM) [5] and degree of irregularity (DOI) [14].

Its aim is to solve the deployment problem of heterogeneous sensor nodes with different communication and sensing range. New sensor nodes are placed to the positions with the most coverage gains while they can maintain the communication connectivity to sink nodes. However, deployment can become difficult when number of nodes increases.

Chen [19] proposes a real time video surveillance system consisting of many low cost sensors and few wireless video cameras. Walchli [20] introduce a novel system of building intrusion detection with a WSN. In order to achieve a good performance, the two systems suggest the topology looking like linear topology to deploy the sensor nodes.

Chapter 3

Heterogeneous Wireless Sensor Networks

3.1 Introduction

Heterogeneous wireless sensor network is a WSN in which sensor nodes are equipped with different kinds of sensors to provide various sensing services. This chapter introduces aspects of HWSN more detail. First, we describe the definition of HWSN in this thesis. Then, we present the target environment on which focused by this research.

3.2 Definition of HWSN

We define heterogeneous WSN as a WSN which of various kinds of sensor nodes whose hardware platform, radio frequency, communication and sensing range differ from each other. Some sensor node hardware is presented in Table 3.1. It shows that almost sensor nodes have

Table 3.1: Some sensor nodes and their hardware and used programming language [6].

Sensor node	Microcontroller	Transceiver	Memory
TelosB	MSP430	250 kbit/s 2.4 GHz IEEE 802.15.4	10k RAM, 48k Flash
SunSpot	ARM 920T	802.15.4	512K RAM, 4MB Flash
MicaZ	ATMEGA 128	TI CC2420 802.15.4	4K RAM, 128K Flash
Iris Mote	ATmega 1281	Atmel AT86RF230	8K RAM, 128K Flash
BTnode	ATmega 128L	Chipcon CC1000	180K RAM, 128K Flash

Table 3.2: The radio frequency of Mica family.

Sensor node	MICA	MICA2	MICAz
Radio module	TR 1000	CC 1000	CC 2420
Radio frequency [MHz]	433/915	315/433/915	2400 to 2483.5

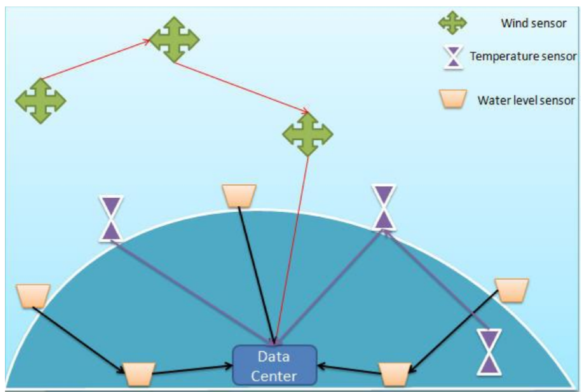
different radio transceivers. Different sensor node hardware differs in radio frequency from one another, and are not able to communicate with nodes with different radio frequencies. For example, although Mica, Mica2, Micaz [6] belong to the same Mica family developed by Crossbow Technology, they cannot send and receive packets with each other by default configuration. Table 3.2 shows the radio frequency (RF) of each platform. In addition, sensor nodes with the same radio modules could still not be able to communicate with each other. For instance, SunSpot [8] and Iris Mote [6] have the same RF of 2.4Ghz, but it is difficult to communication between the two because of the difference of packet construction and data transmission standards.

3.3 The Advantage of Heterogeneous WSN

Because of cost and complexity of node deployment, traditional WSN deployment is always using a single sensor node hardware platform. One kind of sensor node is difficult to provide a wide monitoring, so the sensing ability is to be limited. For example, only either temperature, humidity sensing or fire sensing is to be implemented simultaneously in a traditional WSN. In contrast with the narrow monitoring, a heterogeneous WSN which consists of sensor node hardware platforms with different capabilities, is easy to support a wide monitoring. Temperature, humidity, fire and sound sensing services can be applied.

3.4 Heterogeneous WSN Applications

With the wide monitoring advantage of heterogeneous WSN, many feasible applications can be implemented nowadays and in the future. One of the most popular applications is building management system as illustrated in Fig. 3.2. Managing and monitoring building is to become more simplicity and safety with the support of a lot sensing services. Besides, other systems in which can deploy heterogeneous WSN are greenhouse management system and weather monitoring system as in Fig 3.1.



(a) Weather monitoring system

(b) Greenhouse management system

Figure 3.1: Feasible Heterogeneous WSN Applications

3.5 Target Environment

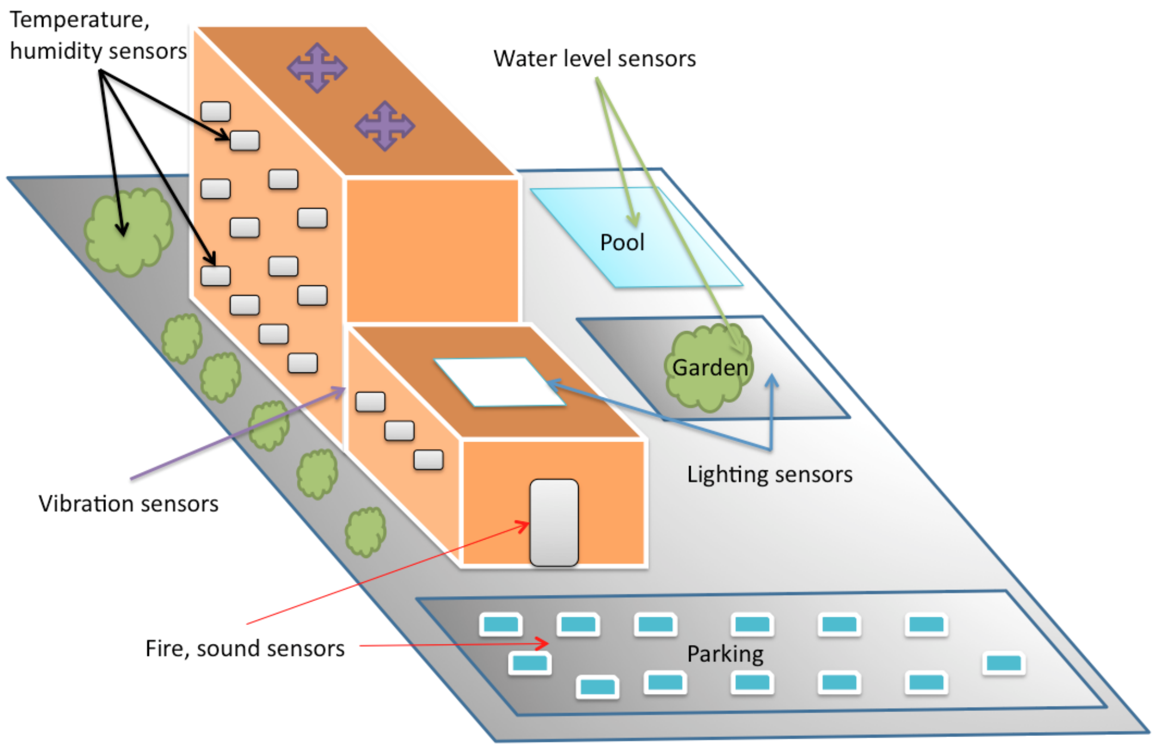


Figure 3.2: A possible scenario of building monitoring

HWSNs could be applied to many environments and scenarios. However, in this thesis, we mainly focus on indoor HWSNs such as a building monitoring system such as described in Fig. 3.2, in which different types of sensor nodes are required to perform the sensing task. In the example shown in Fig. 3.2, temperature and humidity sensors are deployed inside the individual rooms, fires sensors, sound sensors, vibration sensors are attached to hallway and water level sensing nodes are attached to gardens outside the building.

Chapter 4

Analysis of problems of Heterogeneous Wireless Sensor Network

4.1 Introduction

With the target environment outlined above, we present three problem domains of a HWSN deployed in building environment; the packet transmission overhead, cost required for deploying mlutiple sensors, and complexity of deployment.

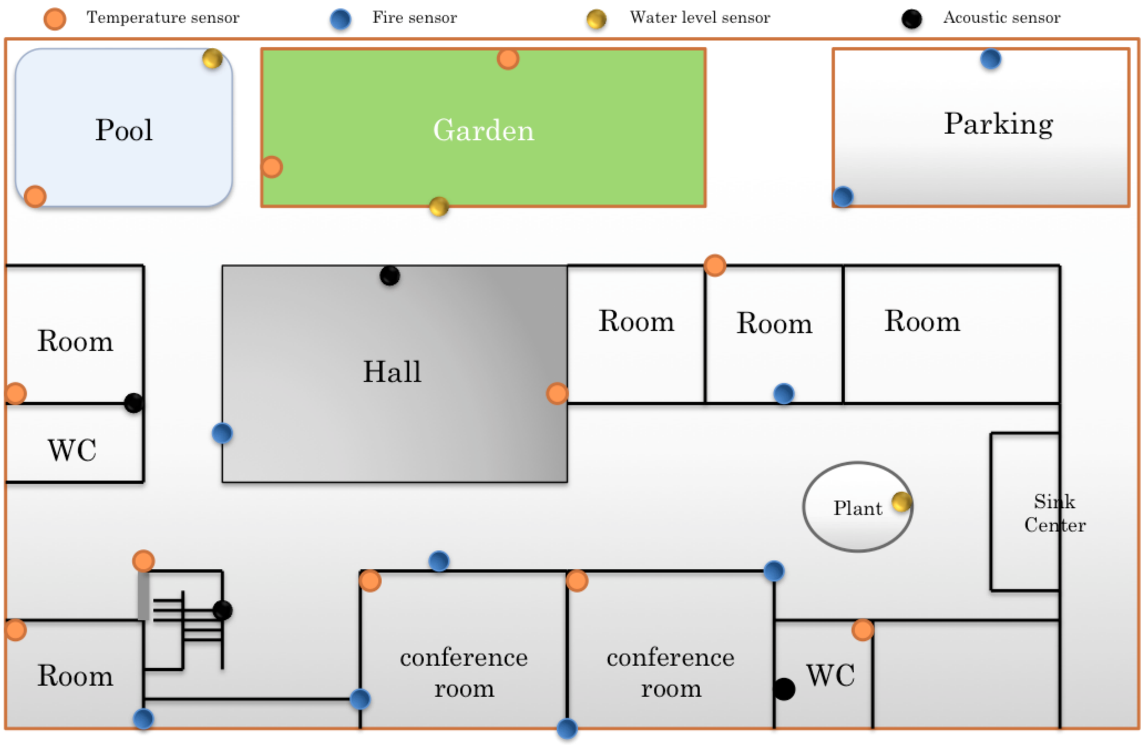
4.2 Packet transmission Overhead

One basic function of WSN applications is to send queries or gathered information between the base station (sink nodes) and the locations where the target phenomena such as fire, movement are observed. Such function often requires multihop packet transmission by a minimum number of hops that can save communication energy and reduce communication latency in dense WSNs or heterogeneous WSNs. Fig. 4.1 is a possible scenario of such HWSNs in a building monitoring system. In this scenario, there are four heterogeneous sensor nodes each described by the colors of orange, blue, yellow and black, respectively representing the sensing task of temperature sensing, fire sensing, water level sensing, acoustic sensing. Because communication is limited to the same mote platforms, packet transmission is redundant. For example, in Fig. 4.1(b), an acoustic sensor in the hall must send its packets through a very long path with many hops to the sink node.

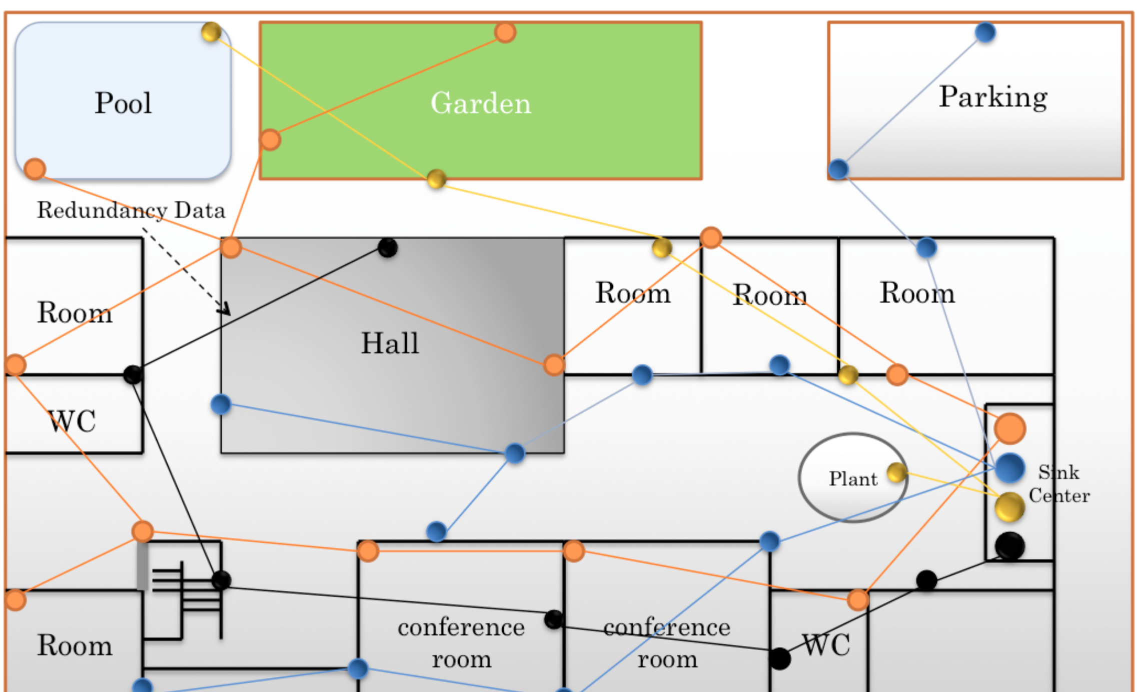
Battery cell is often attached as the source of energy to each sensor node. Because the size of a cell is limited, the amount of energy is also limited. Hence, power saving plays an important role as one of the important requirement. In Fig. 4.2(a), it is observed that the power requirement for sending data increases proportionally by the factor of number of hops. Latency of WSN is an important concern because many applications require rapid data collection, such as fire detection applications. The correlation between data latency and number of hops is shown in Fig. 4.2(b).

4.3 Cost and Complexity of Node Deployment

In order to gather information from distant sensor nodes, the intermediate sensor nodes needs to forward the data to the sink nodes. Therefore, as the deployment environment of the WSN increases, a complementary number of forwarding nodes are required. This results in increase of deployment cost of sensor hardware and the complexity of the deployment.

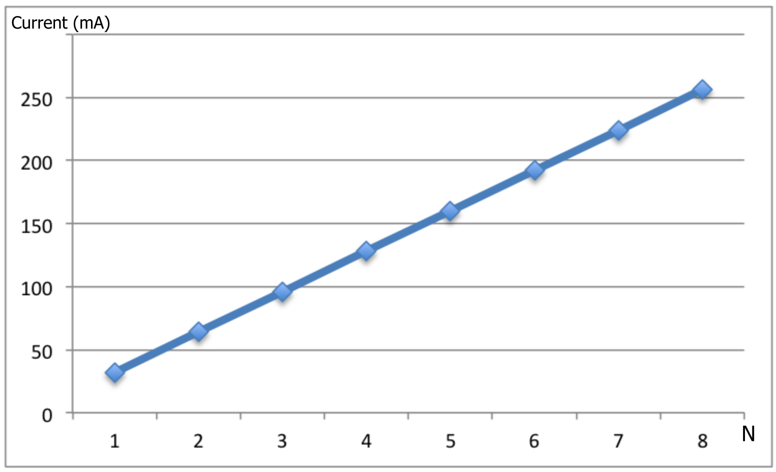


(a) Original Nodes

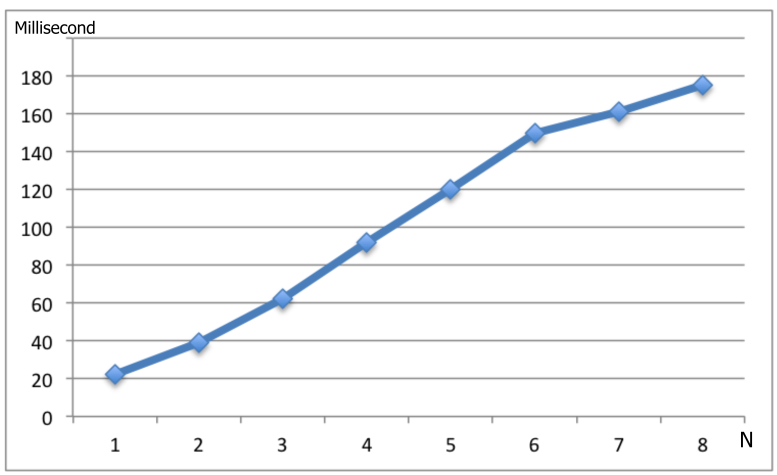


(b) Packet Transition

Figure 4.1: An example of deploying sensor nodes and forwarding nodes



(a) Consumed Power



(b) Delay Time

Figure 4.2: Power consumption and Latency vs. number of hops N

Chapter 5

Proposed Solution

5.1 Introduction

We propose fNode and fMap to deal with problems of packet transmission and complexity of node deployment. In this chapter, we describe the definition of fNode and its qualities. Then we present how to deploy fNode in specific scenarios by using fMap.

5.2 Definition of fNode

The main reason of the problems mentioned above is that many existing sensor platforms have different radio modules and are thus are not able to communicate with each other, which results in inefficient energy consumption, deployment cost and complexity. We aim to challenge this issue by designing fNode, a sensor node can help all sensor nodes deployed in heterogeneous WSNs, which acts as an intermediate node to relay packets of various sensor platforms. The main function of fNode is to convert and forward the packet's format compatible with various platforms. Fig. 5.1 shows a heterogeneousWSN in which fNodes are deployed. In this figure, the acoustic sensor deployed in hall can transmit its packets to the sink node by a shorter path via fNode. In this case, the number of hops is only three while if fNodes are not deployed, six hops are required. In addition, by comparing with Fig. 4.1(b), it shows that the number of forwarding nodes are removed significantly such as the

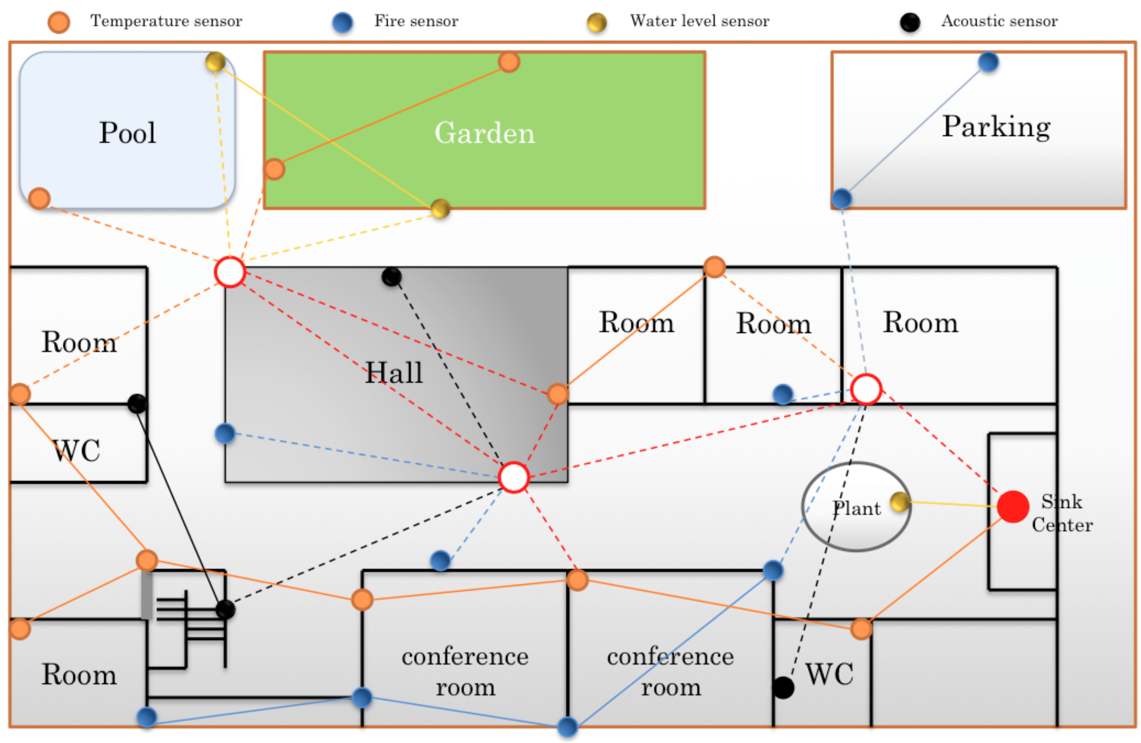
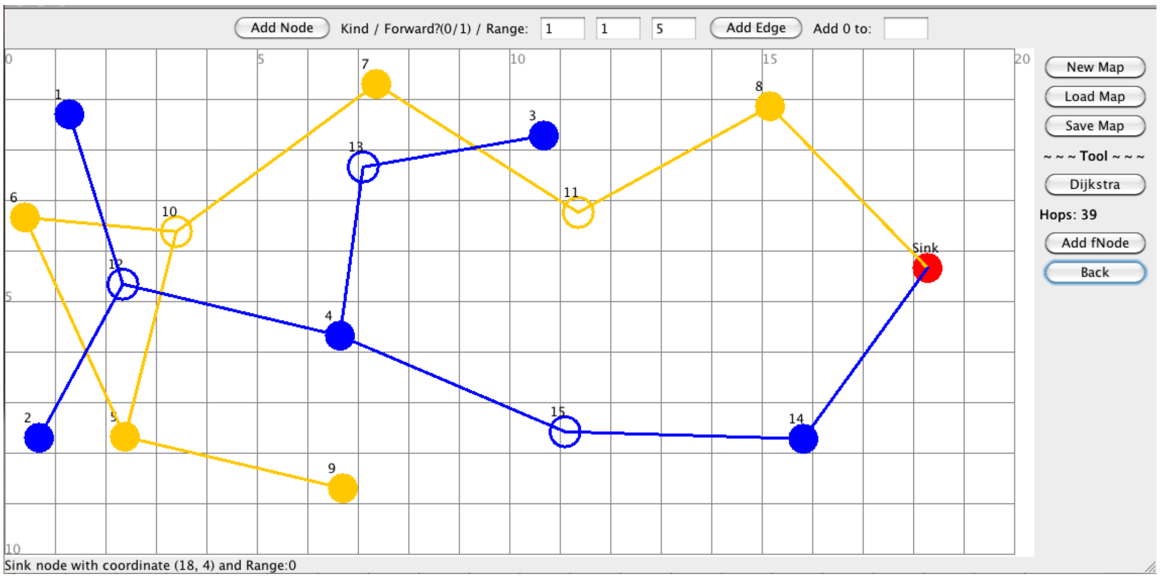


Figure 5.1: An example of deploying fNodes in a heterogeneous WSN

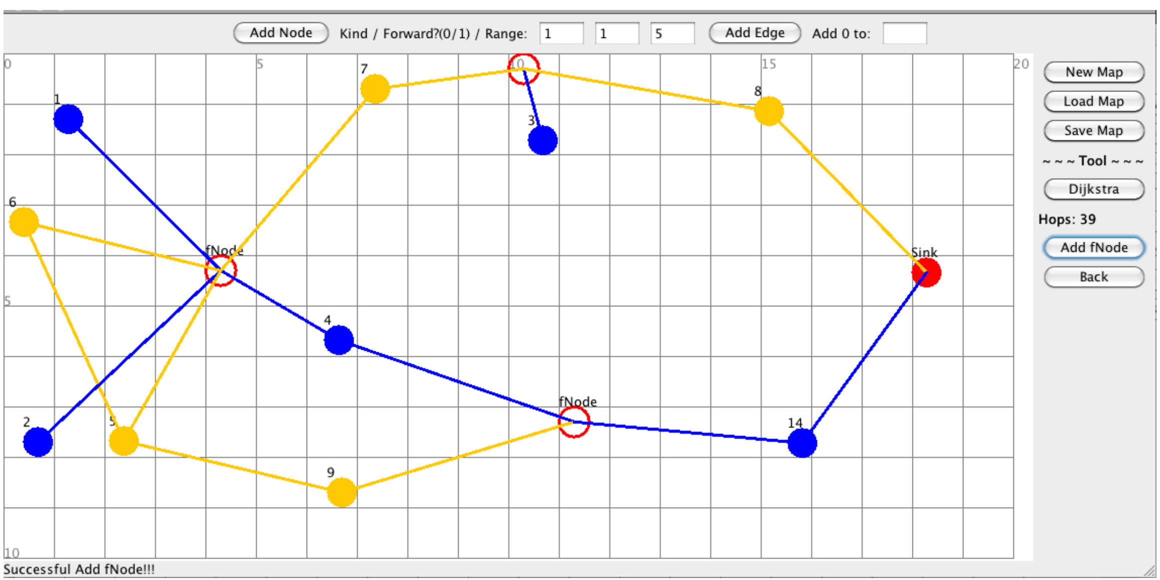
water level and fire forwarding node. In Fig. 5.1, the water level sensors in pool and garden can transmit their packets via fNode deployed near the hall room.

5.3 fMap

In order to minimize the network packet transmission overhead, an ideal deployment scenario of fNode is necessary. We propose fMap to solve the problem of fNode deployment. An example of fMap is shown in Fig 5.2. A possible scenario of heterogeneous WSNs is drawn on the fMap's GUI (Fig. 5.2(a)), which the fMap would import and output the ideal positions of fNodes within the network (Fig. 5.2(b)).



(a) Original Nodes



(b) Used fNodes

Figure 5.2: An example of deploying fNodes by fMap

Chapter 6

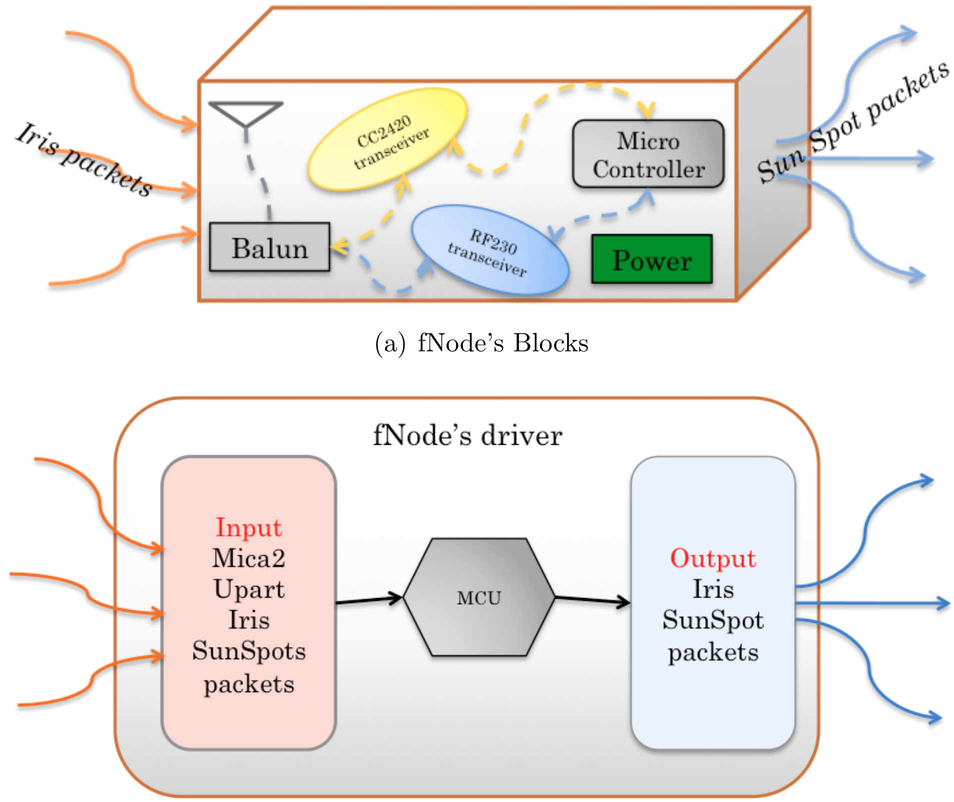
Implementation of fNode and fMap

6.1 Introduction

This chapter describes the implementation of fNode and how to deploy fNodes. First, we present the design of an ideal fNode. Second, the testbed of fNode is described. Then, we propose an algorithm to deploy fNodes in the target environment. We name it fMap. Finally, we explain the usage of testbed fNode and fMap.

6.2 Design of fNode

fNode is one kind of sensor node which plays role as a forward node in heterogeneous WSN. It can receive packets of all kinds of sensor nodes, convert their format and send them to following nodes. For example, it can receive Iris node's packet [6] and transmit them to Sun Spot nodes [8]. Each kind of sensor node has its own radio chip that is different from each other. For instance, Sun Spot node employs the 802.15.4 [10] compatible CC2420 [13] radio chip from Texas Instruments, Iris node uses an 802.15.4 compatible RF230 [15] radio chip, and Mica2 node uses the CC1000 [16] chip [17]. Therefore, in order to be able to collect packets of all nodes, fNode is integrated with CC2420 and RF230 RF transceiver. In addition, because the packet's format of each node is not same, fNode is built with a driver that can understand all packets and convert them into a compatible format.



(a) fNode's Blocks

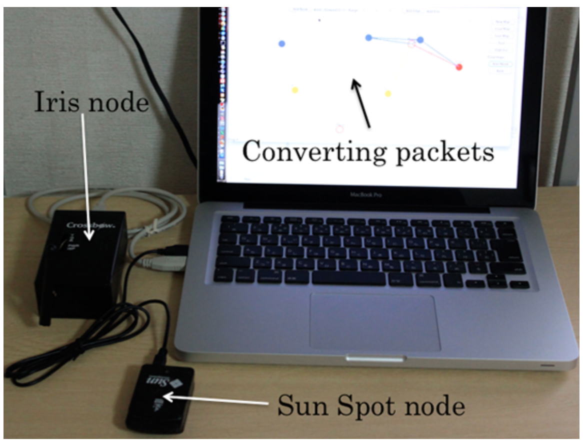
(b) fNode's Driver

Figure 6.1: Design of fNode

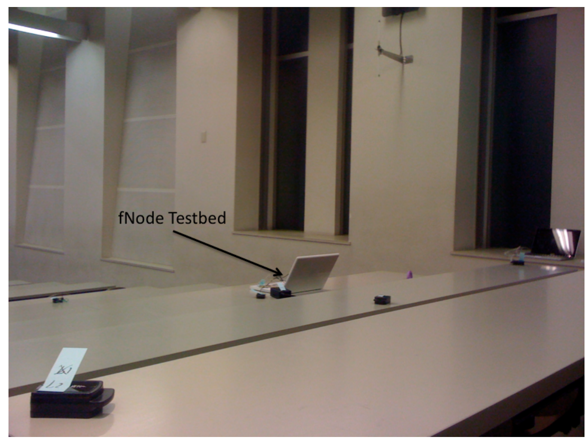
fNode's blocks and driver are shown in Fig. 6.1. In this thesis, the design of realistic fNode and how to create it are not focused on. We target the evaluation of network packet transmission overhead when fNode is deployed in indoor heterogeneous WSNs. The testbed of fNode is introduced in next subsection.

6.3 fNode Testbed

Fig. 6.2 illustrates the testbed of fNode. All kind of sensor nodes are connected with a laptop, playing a role as a fNode. In more detail, we use Sun Spot and Iris node in our testbed. They are to be connected with the laptop by USB cables. This laptop can receive and transmit packets via the sensor nodes. Packets are received from one node on the laptop converted into different formats and then sent to other ones. The converting method is shown in Algorithm 1. When fNode testbed is deployed in a WSN, all its sensor nodes are to be set up in the active state. If a packet comes, its payload will be get by *getPayload()* function. Then, the payload is analyzed about data length, data type and wrapped by *analysePayload()* and *wrapPayload()* functions. Finally, *sendPayload()* function sends it to a certain node with a compatible format analyzed in the previous step.



(a) fNode Testbed



(b) fNode in a WSN

Figure 6.2: fNode Testbed

Algorithm 1: Packet Conversion Algorithm

/* **Note:**
Our testbed fNode uses only Sun Spot and Iris nodes. */

Input : A certain node's packets
Output : Other ones's packets

1: Receive Packets
while *Active* **do**
  Listen for packets coming in
  if *Came* **then**
    Call getPayload()
    Call analysePayload()
    Call wrapPayload()
    Go to 2
  end
end
2: Send Packets
if *Have any request* **then**
  Call sendPayload()
end

6.4 Implementation of fMap

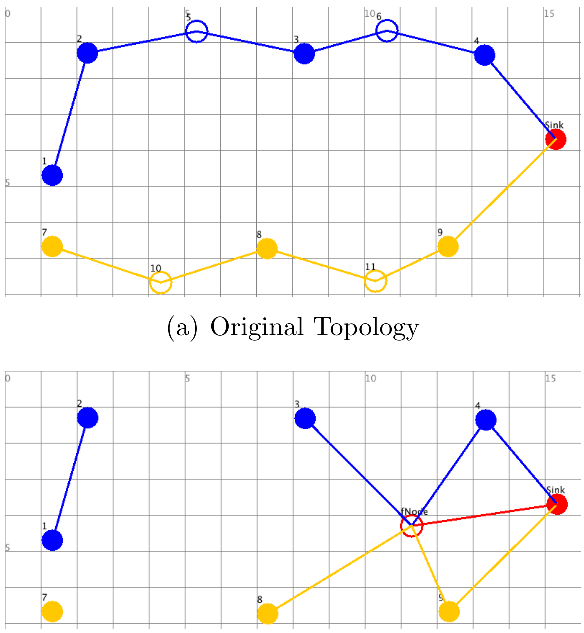
fMap's algorithm is shown in Algorithm 2. Each node is defined by (x, y) coordinate and r radio range. Dijkstra algorithm is used to calculate the minimum number of hops in order to transmit packets from a certain node to a sink node. First, it removes nodes that plays role as a forwarding node. Second, the relation among new nodes is added as illustrated in Fig. 6.3(b). It means that if A node can send packets to B node, the *(A, B)* relation is equal to 1, otherwise is 0. Then, fMap begins finding fNode's ideal positions. Each one fNode is added until all sensor nodes can send their packets to the sink node as illustrated in Fig. 6.3(c) and Fig. 6.3(d). The best position of fNode is estimated by reviewing all deployable positions in indoor heterogeneous WSN and choosing the position on which sum of hops of all sensor nodes is minimum. The output of this algorithm is the coordinate of fNodes in HWSN.

Algorithm 2: The ideal deployment scenario

/* **Note:**
$\boldsymbol{A}$ node has (x_a, y_a) coordinate and $\boldsymbol{r}$ radio range.
$\mathcal{V}_a$ is set of nodes that $\boldsymbol{A}$ can transmit packets to.
If Distance$(\boldsymbol{A} \rightarrow \boldsymbol{B}) \leq \boldsymbol{r}_a$ then $\boldsymbol{B} \in \mathcal{V}_a$.
$\boldsymbol{d}_a$ is minimum number of hops which necessary to send $\boldsymbol{A}'s$ packets to a sink node.
$\boldsymbol{d}_a$ is calculated by Dijkstra algorithm [18]
$\mathcal{D}$ is $\sum$ hops of each node. */

Input : The (x, y) coordinates of sensor nodes, forwarding nodes and their radio range - r
Output : The (x, y) coordinates of fNodes

```
1: Remove all forwarding nodes in HWSN
2: Add the relation among new nodes.
if Distance(A → B) ≤ r_a then
|  B ∈ V_a
end
3: Find ideal positions of fNodes.
while all nodes are not conneted do
    Add a new fNode
    for all deployable positions do
        Calculate D
        if D < current D then
            Current D = new D
            Set fNode's position
        end
    end
end
```



(a) Original Topology (b) Removing all forwarding nodes

(c) Topology after one fNode added (d) Topology after two fNode added

Figure 6.3: fMap algorithm's steps

We provide a GUI, written by Java, to implement fMap. It looks like Fig. 5.2. In order to use it, firstly, the program draws nodes and moves them to suitable positions on the fMap's map. Then, fNode's positions will be calculated by simply clicking the fNode button of GUI.

Chapter 7

Experiments

7.1 Introduction

This chapter presents the experimental results of our fNode and fMap. We describes the experimental method and how to conduct experiments in Section 7.2. Then, we present topologies of WSN used in our experiments. Finally, the results are shown in Section 7.4.

7.2 Experimental Method

We have performed our experiment inside an indoor classroom environment (20m x 30m) with minor radio blocking obstacles such as desks and chairs as illustrated in Fig. 7.1(a). We have deployed two MacBooks as our current implementation, and Sun Spot and Iris nodes are used as sensor devices in our experiments (Fig. 7.1(b)). First, we have deployed the sensor nodes and a sink node with the two topologies mentioned in section 7.3 in our target environment. Then, we have measured the sum of hops, the power usage and the packet transmission latency of each node that is necessary to transmit its packets to the sink node. We then use fMap to calculate positions of fNode and deploy fNodes with existing sensor nodes, and perform the same measurement as above.

(a) Classroom Environment

(b) Sensor devices and MacBooks as fNode testbed

Figure 7.1: Experimental Environment

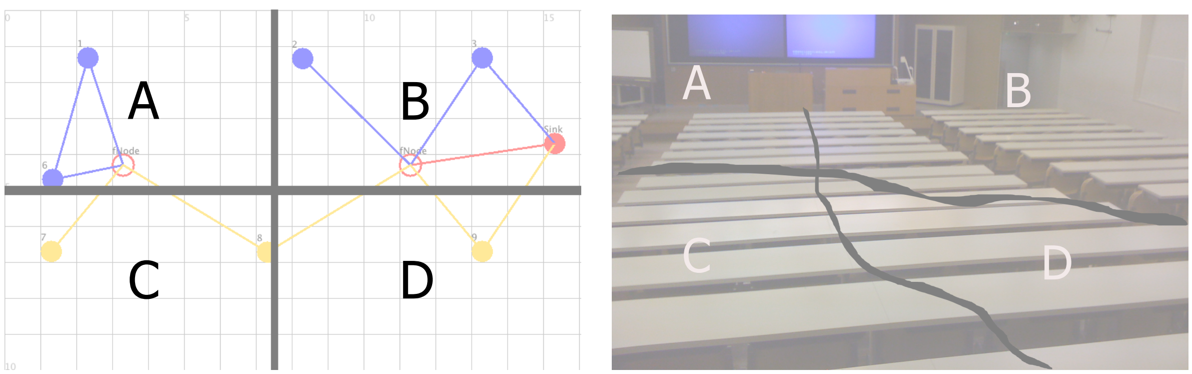


Figure 7.2: The experimental Space of fMap

7.2.1 How to evaluate fMap

In order to evaluate the effectiveness of using fMap, fNodes are deployed at some different positions and conduct the same experimental steps like above. Because deploying fNodes at all positions of experimental environment is very difficult, we divide our experimental space up into parts whose width and height are same with the maximum of communication range of sensor nodes deployed. Our experimental space's area is about *20m x 30m* and the communication range of Sun Spot and Iris nodes is *5m - 10m* after adjusted. Therefore, we divide it into four parts that marked with *A, B, C, D* label, as illustrated in Fig. 7.2.

First, two fNodes are deployed in the A part and their numbers of transmitted packets are collected. Then, they are deployed in the A part, the B part respectively and perform the same measurement as above. As a result, we can collect the result of measurement of 10 deployment cases: (A A), (A B), (A C), (A D), (B B),(B C), (B D), (C C), (C D), (D D).

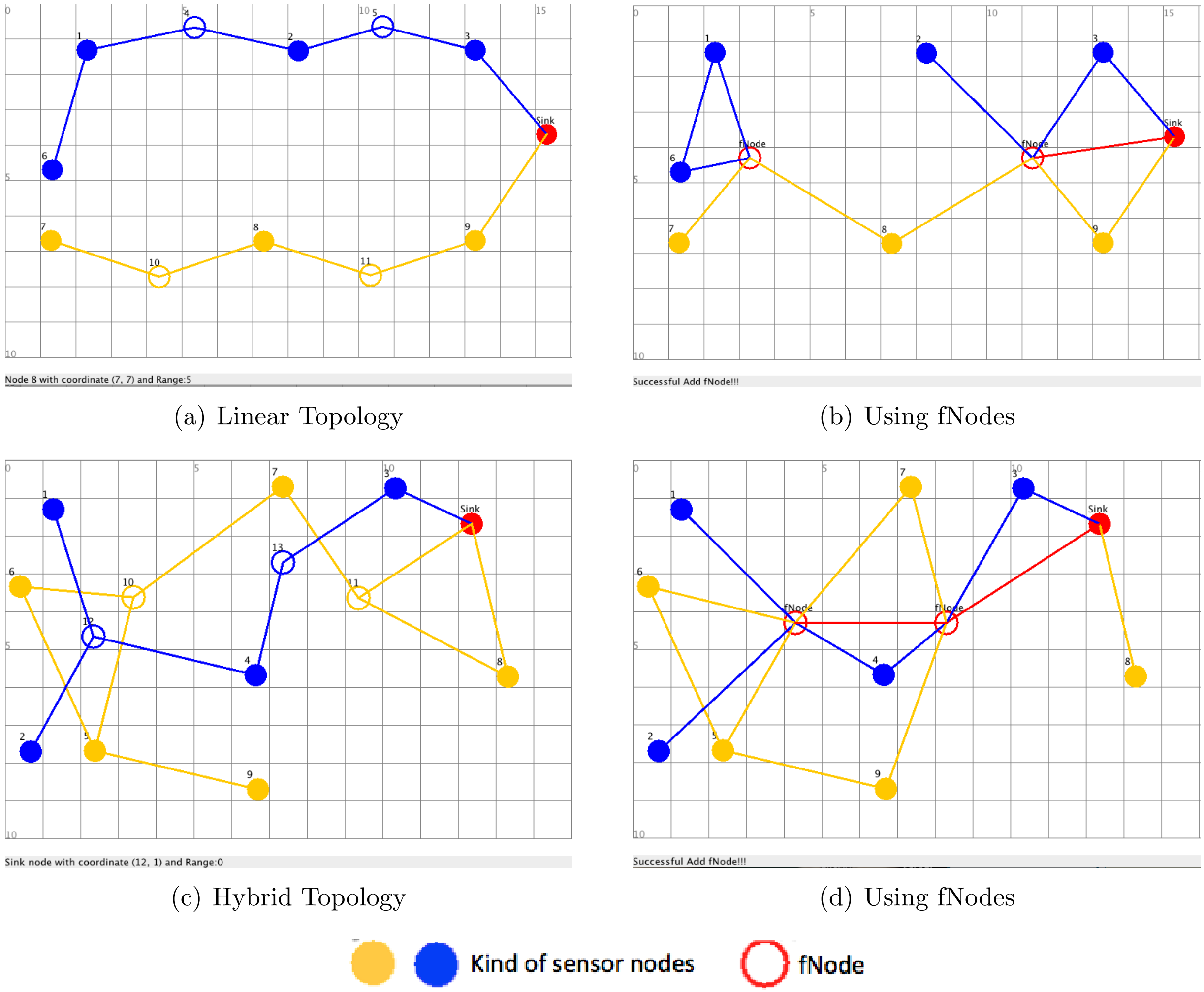
7.3 Testbed Topology

We present the experimental results of fNode under two deployment topologies, linear and hybrid. Many indoor WSN applications are deployed with these two topologies. The works mentioned in section 2.4 and sensor nodes of the building monitoring system in [21] are deployed with the linear topology. This topology is used because the topology control can be optimized. On the other hand, Guinard [22] uses the hybrid topology in his WSN design tool since sensor nodes will become highly correlated. The linear topology in heterogeneous WSN (Fig. 7.3(a)) means the topology construction of each kind of sensor nodes is not to overlap each other ’s one. In contrast, the hybrid topology (Fig. 7.3(c)) means that the overlap of topology construction can happen.

Fig. 7.3(a) and 7.3(c) illustrate the original topologies on the fMap. On the other hand, Fig. 7.3(b) and 7.3(d) describe how fNodes are deployed by fMap's algorithm. All forwarding nodes are replaced by fNodes. In the two cases of deployment topology, fMap calculates that at least 2 fNodes are required to ensure the interoperability of these WSN.

7.4 Experimental Results

The total number of transmitted packets of the original WSN and WSN deployed with fNode are measured and estimated at the sink node. The average of packets is shown in Fig. 7.4(a). We have observed that in the two cases of fNode's deployment topology, the packet transmission is reduced by approximately 35%. In the linear topology case, if 18 hops



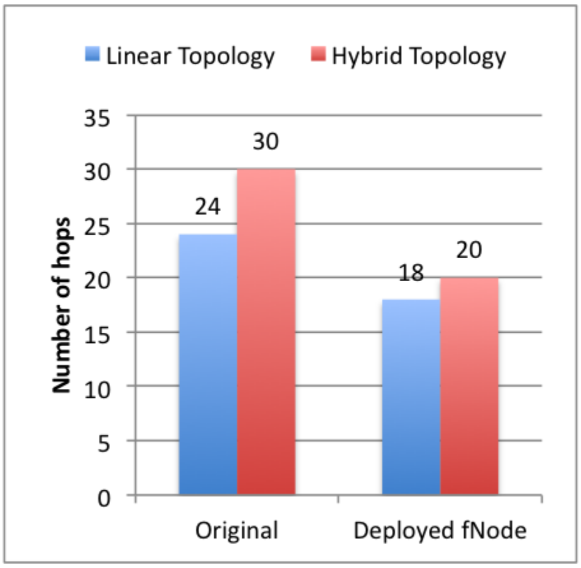
(a) Linear Topology (b) Using fNodes

(c) Hybrid Topology (d) Using fNodes

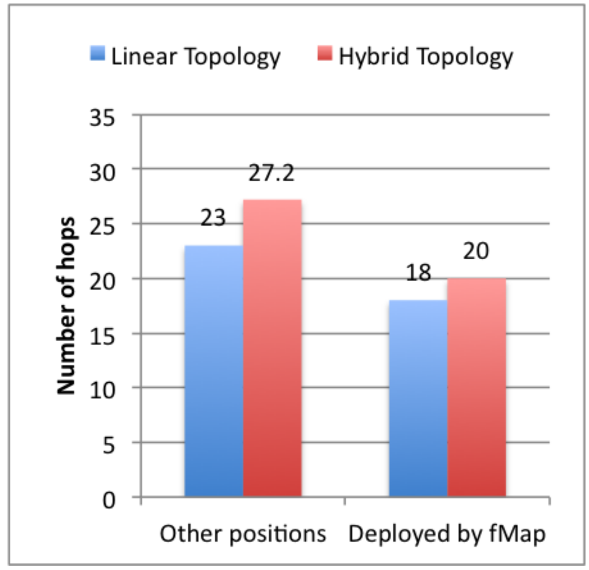
Figure 7.3: Original WSN and WSN in which fNodes are deployed

of using fNode compare with 24 hops of original topology, the number of hops decrease by 6 hops. In addition, in the hybrid topology case, 10 hops can be removed. Besides, the total quantity of the sensor nodes are also reduced which contributes to the cost reduction of sensor network deployment.

The average value of the 10 deployment cases of fNodes is shown in Fig. 7.4(b) - Other positions. This shows that by using our algorithm (fMap) for deploying fNodes, the number of transmitted packets is reduced at the most. In addition, it is observed that in almost the case, when fNodes are deployable, total number of hops is less than the original deployment's



(a) Original vs. fNode



(b) fMap vs. Others

Figure 7.4: Total number of transmitted packets (number of hops)

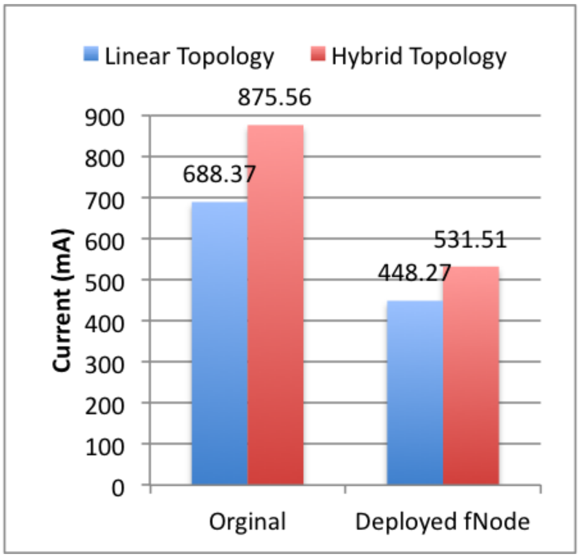
one (Fig. 7.4(a) - Original).

In order to evaluate exactly the effectiveness of using fNodes, the power consumption of nodes and the latency of the HWSN are estimated. Results of receiving and transmitting power in [12] [17] are used in our experiments. Total power consumption is calculated by the formula:

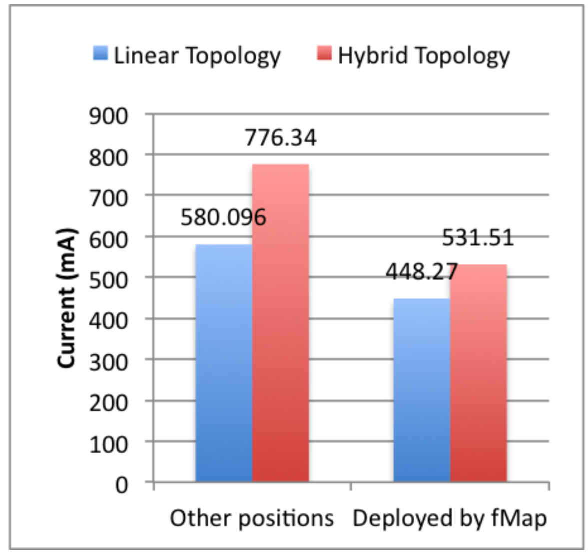
$Power = \sum(Receiving + Transmitting) * Kind\ of\ sensor * used\ Time$

The average transmission power consumption per deployment case is presented in Fig. 7.5. It shows that by using fNodes and fMap, the power consumption is less in the two cases. In the linear topology case (Fig. 7.5(a)), if 488 mA of using fNode compare with 688 mA of original topology, the energy consumption decrease by 33%. In addition, in the hybrid topology case, 39% can be removed.

Total latency of each experienced case is measured by sum of receiving and transmitting time (delay time) in each node. Through our experiments, we find out that delay time of Sun Spot and Iris node are 23ms and 4ms respectively. The result of latency is shown in



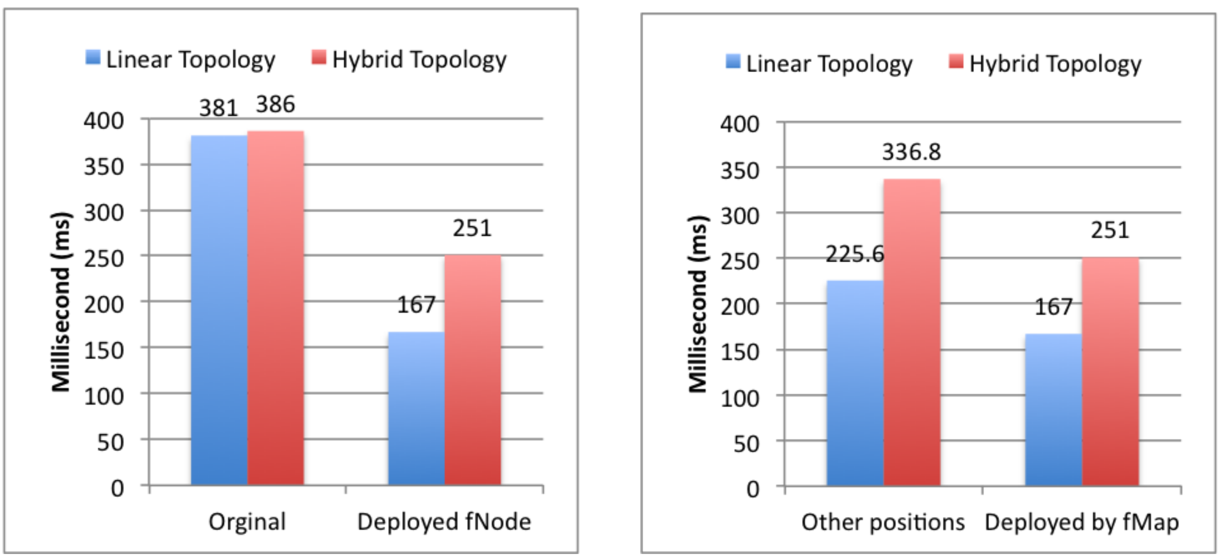
(a) Original vs. fNode



(b) fMap vs. Others

Figure 7.5: Transmission Power of all nodes in each case

Fig. 7.6. As expected, it is observed that the latency of fNodes is shorter than the original case. The delay time can be reduced 35 - 40%, especially the linear topology case. This is because of the minimum packet transmission of fMap in Fig. 7.4.



(a) Original vs. fNode

(b) fMap vs. Others

Figure 7.6: Latency Time in each case

Chapter 8

Conclusion

We have proposed fNode, a sensor node capable of forwarding packets of different communication architecture to reduce packet transmission overhead in indoor heterogeneous WSNs. We have evaluated our work under real-life environments, and our deployment of fNode have successfully reduced the packet transmission overhead, power usage and the latency of the network in our testbed scenario by approximately 30%. Our experimental results provide valuable insight into the benefits of fNode, but they are only the first step. A realistic fNode which can deploy and be applicable in a WSN environment is necessary. As our future work, we aim to implement fNode on a specifically designed hardware platform, and deployment under a larger scale WSN.

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