# Prioritized Self-Configuration for Self-Organized Sensor Networks

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***Abstract*—Self-configuration of sequence order, including network addresses and data reporting times, is important in a sensor network. This process empowers sensors to dynamically assign short-length addresses, thereby enhancing energy efficiency in sensing-data reporting. In the absence of configuration servers, sensors self-organize into function roles of sever-client, enabling the dynamic formation of address servers to assign short-length addresses to sensors. This paper addresses the configuration distance problem with an aim of shortening the distance of configuration routes between the address server and clients. We propose a prioritized self-configuration method that employs spatial-temporal control of configuration according to the topological distance to the client server in each round of address configuration. Numerical evaluations are carried out to verify the performance of the proposed method. The evaluation results show that the proposed method enables a significant decrease of up to 30 percent in the configuration distance.**

***Keywords-Self-organization; smallest-size address; self-configuration; high-priority zone.***

## I. INTRODUCTION

Self-configuration in a Wireless Sensor Network (WSN) is crucial for several key benefits. It facilitates the assignment of unique identifiers to each sensor node, enabling individual device identification and communication. Furthermore, self-configuration enables the utilization of short-length addresses, which significantly enhances energy efficiency by reducing the overhead associated with data packet transmission. Because sensing data can be only a few bytes long, address size becomes a critical factor that directly influences the energy consumption of each transmitted packet [1] [2] [3] [4].

Numerous methods of address configuration exist within Internet of Things (IoT) networks and ad-hoc networks [5] [6] [7]. Dynamic address assignment based configuration technique is a practical and straightforward approach to assigning unique addresses within an ad-hoc network [7] [8] [9]. For mobile ad-hoc networks, mobility and network partitions pose significant challenges in addressing and configuration. To address these issues, numerous configuration methods have been developed [10] [11].

On the other hand, sensor networks generally exhibit a static topology but demand the use of short-length addresses or sequence number for energy efficiency [3] [12] [13]. The self-organized server-client functionality plays a key role in the configuration of short-length addresses or sequence numbers [2] [14] [15]. The unique and short-length address or sequence number can be configured by a dynamic server-client structure, which are self-organized among sensors. Wireless mutlithop routing are employed for communication between the address server and clients. The topological distance between the server and an client is called the configuration distance. The configuration distance can be represented by the route length in terms of hops between the address client and server.

In this paper, we address the configuration distance problem in a sensor network. A large configuration distance significantly increases communication resource consumption and introduces delays. This problem becomes particularly impactive in large sensor networks.

To solve this problem, we propose a method that controls the configuration correlation between sensor nodes. The basic idea is that each client starts to configure an address with a high priority by using a probability function to control its access to the address server. The clients avoid initiating a configuration request when the topological distance between them is substantial, considering both spatial and temporal aspects of network connectivity.

Numerical evaluations are carried out to validate the proposed methods. We implelement the proposed scheme of prioritized configuration in a C++ based simulation, with comparasion to the basic method of dynamic server based configuration [2]. The evaluation results illustrate the significant effectiveness of the proposed method in terms of configuration distance and configuration overhead.

The rest of the paper is structured as follows. In Section II, we present system model and basic concept. In Section III, we introduce the proposed method of prioritized configuration with spatial-temporal control. In Section IV, we introduce the numerical evaluation and present evaluation results. Finally, we conclude the article in Section V.

## II. SYSTEM MODEL AND BASIC CONCEPT

### A. Network Model

A sensor network can be represented as a graph $G = (V, E)$, where V involves sensor nodes, and E is the collection of wireless links between sensors. Each sensor node has capabilities of sensing, computing, and wireless communication. The address of each sensor node is configurable. To save energy consumption, the address of a sensor and its size can be set up in an on-demand manner rather than being a predefined long-size address before networking. Since sensor node has a power constraint and short data size in transmission, the size of address is not ignorable. In a self-organized sensor network, sensor nodes are expected to cooperatively perform the role of network infrastructure, automatically configuring sensor nodes into network.

### *B. The Basic Concept of Dynamic Configuration Organization Method*

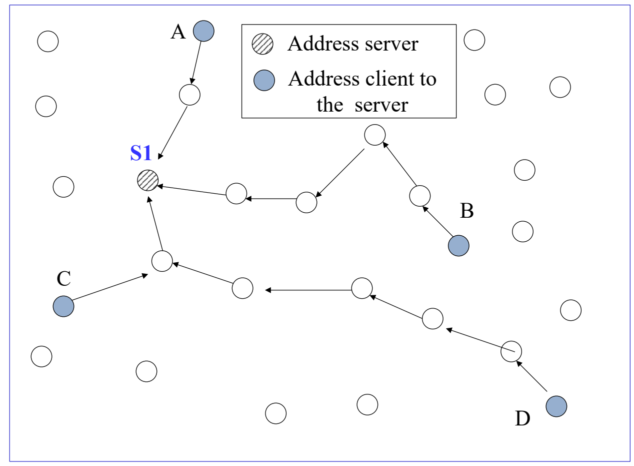
The dynamic configuration organization method attempts to configure a network-wide unique address for each sensor node [2]. In order to use a potential smallest address space, the self-configuration mechanism assigns address sequentially from low to high without the overuse of address space. Such a sequential assignment of node addresses desires a deterministic operation rather than an opportunistic operation so as to keep the consistency of address configuration in the self-organized sensor networks. Hence, a self-organized server-client structure is proposed. An address server is autonomously selected and serves the address configuration with a term limit. After a serving term expires, another sensor will be selected as the address server.

### *C. Problem*

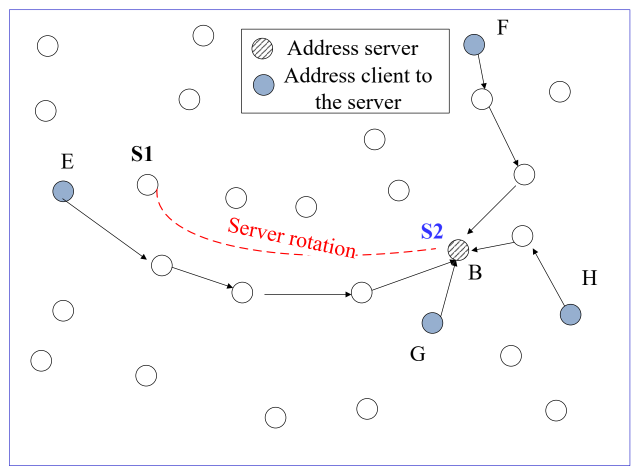
The problem addressed in this paper is the configuration distance problem in address configuration. The configuration distance is measured by the route length of address request and reply between address server and client. The configuration distance has a significant impact on energy consumption as well as the delay of address configuration. Meanwhile, the previous methods have not considered the efficient management of routes in the address configuration, leading to a scalability problem of the route length between the address server and the sensors that request an address.

Figure 1 shows an example of the configuration distance problem in dynamic self-configuration. In Figure 1(a), S1 is the address server. Node A, B, C, D are address clients that successfully issue address requests to S1. Node D needs to send the address request with a route length of 6, although there are nodes near to the server.

In Figure 1(b), S2 (node B) is the address server, which plays the server role after S1 transfers the server role to it. Node E, F, G, H are address clients that successfully issue address requests to S1. Node E needs to send requests with a route length of 4 although there are nodes near to the server.




(a) Address configuration with server 1




(b) Address configuration with server 2

Figure 1. Configuration distance problem in the address configuration of a large WSN.

## III. Prioritized Configuration Method with Spatial-Temporal Control

We propose a spatial-temporal control based prioritized configuration method to the reduce the configuration distance. In a self-configuration procedure of a WSN, the server-client interaction is carried out using address request (AREQ), and address reply (AREP). For a sensor node, it needs to issue an AREQ to the address server with configuration contention among other sensor nodes. The proposed method differentiates the priority of configuration contention among sensors according to the topological distances between the address server and address clients.

As shown in Figure 4, there is a high priority zone around each address server. The priority zone contains a set of sensors that have a short topological distance to the address server. In the example shown in the figure, the radius of the high priority zone is two hops. The sensors in the high priority zone are assigned with a higher probability to obtain configured addresses from the address server than sensors outside the zone. In the example shown in Figure 4(a), the sensors A, B, C, D in the high-priority zone have the addresses configured by server 1. After the role of address server is shifted to server 2, sensors E, F, G, H, which are in the high priority zone have their addresses configured by the address server 2.

Algorithm 1 introduces the proposed algorithm for configuration control at sensor nodes of address clients. For each address server, address clients have different priorities to request the configuration response. Suppose that there is a time pool for a sensor node to issue an AREQ in a server term. In each time slot, a sensor node that has no address, attempts to request an address from the server. At time slot $i$ in a server term, a node contents for a configuration seat by a probability control mechanism. The state of the configuration seat refers to whether the node can issue an AREQ in the time slot. There is a default



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number pool in the range of $(0, Timepool1)$ for each node. A node randomly selects a control number from the configuration number pool. If the selected number matches with a predefined small number such as 1, the state configuration seat is then set to 1.

Therefore, to control the configuration probability based on the control number, we design a priority-based method based on the topological distance to the address server. According to the topological distance to the address server, the node zone is divided into two parts. The first part is the high priority zone, which is the set ZoneH that contains sensor[i] with the topological distance $TopoDist(i, ServerNow) < Threshold$. The second part is the low priority zone, which is the set ZoneL that contains the sensor[j] with the topological distance $TopoDist(j, ServerNow) > Threshold$. The $Threshold$ can be set to a certain value such as 3 hops, 5 hops, and so on.

In the high priority zone, the control number is generated as $ControlNum = Rand(0, Timepool2)$, where $Timepool2 = \frac{Timepool1}{k}$, where k is an integer such as 10. The hit probability of configuration state being 1 is $1/(Timepool1/k) = k/Timepool1$. In the low priority zone, the control number is generated as $ControlNum = Rand(0, Timepool1)$. The hit probability of configuration state being 1 is $1/Timepool1$.

Algorithm 2 shows the dynamic configuration method based on the server term control at address servers. Note that, in a Self-configuration of a WSN, the server-client interaction is carried out in address request and address reply. The server term control allows the dynamic generation of address servers among sensors, enabling the energy balancing for the configuration service at address servers. The locality AREQ and AREQ brings out merits of short route-length, low resource consumption, as well as low vulnerability to transmission failure and recovery cost.

## IV. Numerical Evaluation

We carry numerical evaluation by C++ based simulation, in which the proposed method is implemented. The basic simulation setup is described in Table I. Two approaches are studied: the basic method of dynamic server based configuration [2], and the proposed scheme of prioritized configuration. The main metric employed in the simulation is the configuration distance in terms of hops, and the configuration overhead. The main evaluation target is to verify the efficiency of address or sequence auto-configuration in terms of configuration distance and configuration overhead. Figure 5 shows the setup of topoplogy of the network with 90 nodes in the evaluation. The second network scenario that employs 160 nodes has a topology of the same width of 100 m to the network with 90 nodes, but with a height of 160 m.

Figure 6 shows the average configuration distance (route length of AREQ/AREP) of sensor nodes in the scenario in which the network size is set to 90. For the conventional method of dynamic server based configuration, the average route length of configuration is about 6. In the proposed method of the prioritized configuration, the shortest configuration distance is achieved when the radius of the high-priority zone is set to 5 hops. With high-priority zone being set to 5 hops, the the results of configuration distance is 4.11 hops, which reduces 30 percent of configuration distance (route length) in the configuration. A very small priority-zone leads to the few nodes are enabled for prioritized configuration. A very large priority-zone weakens the impact of prioritized effect in configuration, leading to that the node faraway from the address server also have high probability to get an address being successfully configured

**Algorithm 1** Prioritized configuration control at each sensor node.

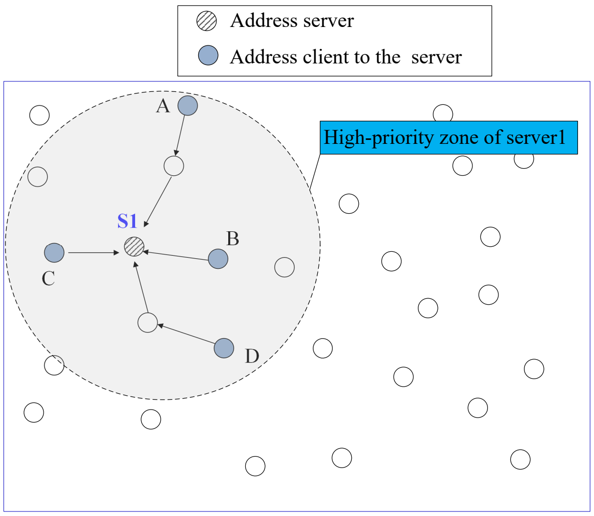
Input: network topology, Timepool1, TimePool2
$Timepool2 \leftarrow \frac{Timepool1}{K}$
**if** $ConfigurationState == 0$ **then**
    **if** $InHighPriorityState == 1$ **then**
        $ConfigSeat \leftarrow Random(0, Timepool2)$
    **end if**
    **if** $InHighPriorityState == 0$ **then**
        $ConfigSeat \leftarrow Random(0, Timepool1)$
    **end if**
    **if** $ConfigurationSeat == HitNum$ **then**
        Issue a request to the address server
    **end if**
    **if**
        Obtaining an address from the server **then**
        ConfigurationState $\leftarrow 1$
    **end if**
**end if**

Figure 2. Algorithm of prioritized configuration control at each sensor node.

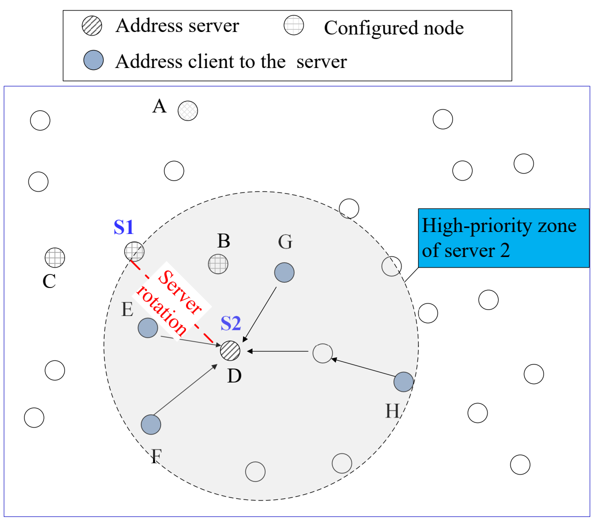
**Algorithm 2** Serving term control.

Data Input: Serving term, network topology
**for** $i = 1 \rightarrow N$ **do**
    ConfigurationState[i] $\leftarrow 0$
**end for**
ServerID1 $\leftarrow RandomlySelectedID$
ConfigurationFinishState $\leftarrow 0$
**while** $ConfigurationFinshState == 0$ **do**
    **if** $ServerRotationState == 0$ **then**
        Configuration of the selected nodes
        **if** $ServingCount == Term$ **then**
            $ServerRotationState \leftarrow 1$
            $LastID \leftarrow LastConfiguredID$
            $NextServerID \leftarrow LastID$
        **end if**
        Update ConfigurationFinshState
        Update server rotation state
    **end if**
**end while**

Figure 3. The algorithm of serving term control at the self-organized address servers.




(a) Address configuration with server 1




(b) Address configuration with server 2

Figure 4. Dynamic priority-zone based configuration control.

from the address server.

Figure 7 shows the average configuration distance (route length) of sensor nodes in the scenario in which the network size is set to 160. For the conventional method, the average

TABLE I. SIMULATION SETUP.

| Basic Simulation Setup | |
|---|---|
| Parameters | Setup |
| Number of nodes in the network | 90, 160 |
| Server term | 10 |
| Communication range | 10 m |
| Timepool1 | 200 |
| Timepool2 | 20 |
| Rounds of simulation | 50 |

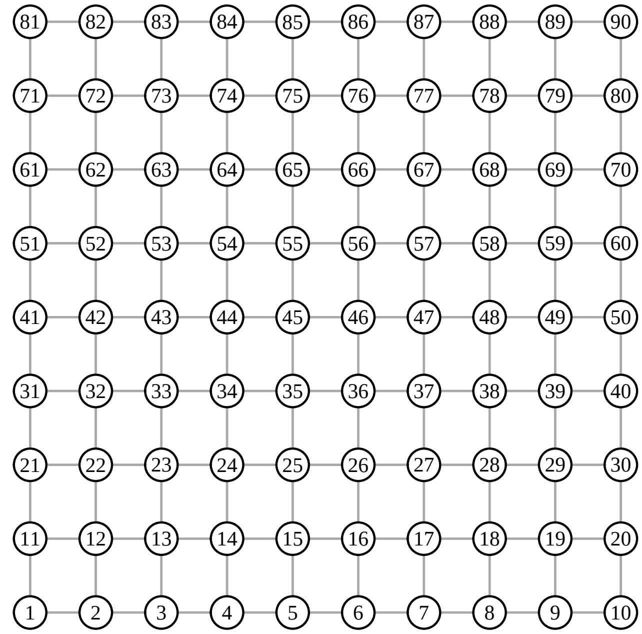



Figure 5. Evaluation scenario of 90 nodes.

route length of configuration is about 8.27. In the proposed method of the prioritized configuration, the shortest configuration distance is achieved when the radius of the high-priority zone is set to 5 and 6 hops. With the high-priority zones being set to 5 and 6 hops, the results of configuration distance is 5.47 hops, which reduces more than 33 percent of configuration distance in the configuration.

Figure 8 shows the average configuration overhead of sensor nodes in the the network with 90 nodes. For the conventional method of dynamic server based configuration, the average configuration overhead is about 5332. In the proposed method of the prioritized configuration, the minimum configuration overhead is achieved when the radius of the high-priority zone is set to 5 hops. With the setup of the optimal priority zone, the results of configuration overhead is 3803, which reduces 27 percent of configuration overhead in the configuration compared with the convention approach.

Figure 9 shows the average configuration overhead of sensor nodes in the the network with 160 nodes. For the conventional method of dynamic server based configuration, the average configuration overhead is about 16891. In the proposed method of the prioritized configuration, the minimum configuration overhead is achieved when the radius of the high-priority zone is set to 5 hops. With the setup of the optimal priority zone, the results of configuration overhead is 12210, which reduces 28 percent of configuration overhead in the configuration compared with the convention approach.

## V. CONCLUSION AND FUTURE WORK

This paper addressed the configuration distance problem in a self-organized WSN. The large WSN desires a short configuration distance to avoid the large resources consumption

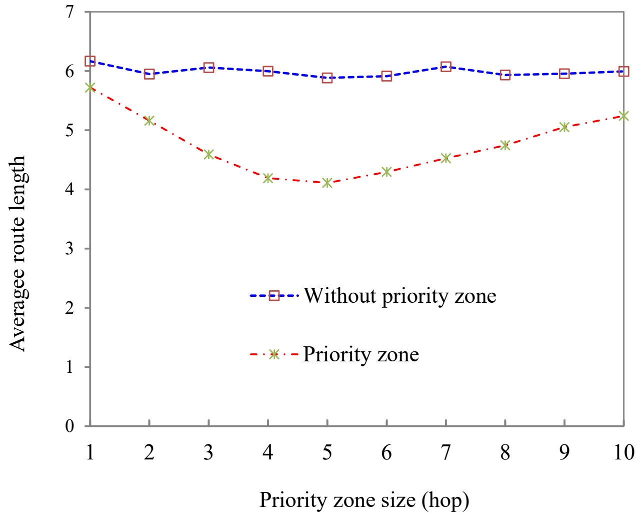



Figure 6. Average route length in network with 90 nodes.

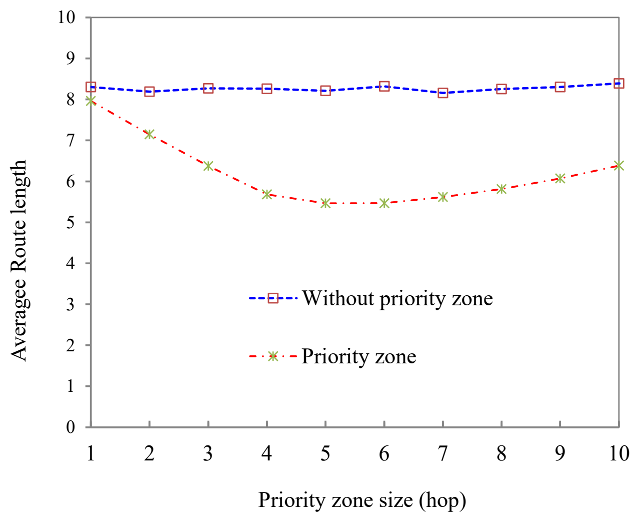



Figure 7. Average route length in network with 160 nodes.

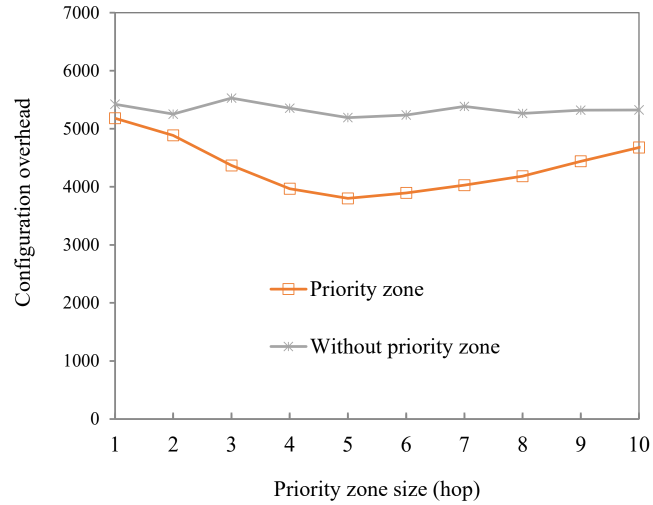



Figure 8. Configuration overhead in network with 90 nodes.

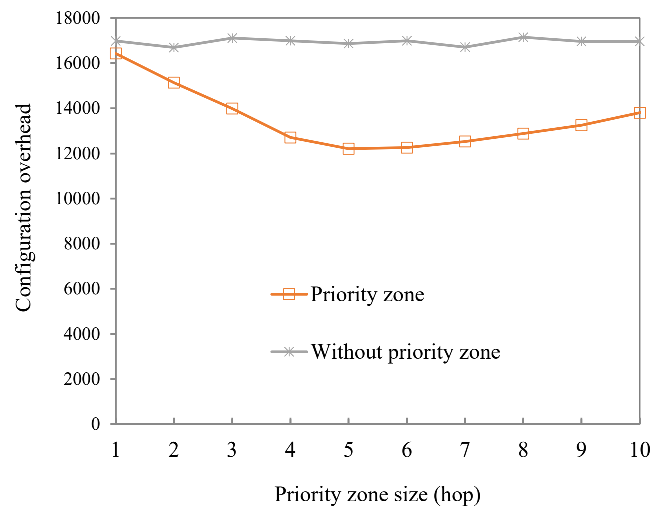



Figure 9. Configuration overhead in network with 160 nodes.

and link delay in auto-configuration of small-size addresses. We propose a prioritized configuration method with probability control based on spatial-temporal association between address clients and server. The evaluation results show the effectiveness of the proposed method in reducing the configuration distance. We find that there is an optimal setup of high-priority zone for the configuration to enable the shortest configuration distance. The short configuration distance is considered to have a significant impact on reducing the configuration delay and energy consumption at sensor nodes. Future work includes the study of adaptive setup of the priority zone for optimizing the configuration performance.

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