Wireless Sensor Networks Model Based on Cellular Automata

Yijun Wang[1, *], Yushan Mei [2]

[1]College of Electronic & Information Engineering, Changchun University of Science and Technology Changchun 130022, China

[2]Changchun China Optical Science & Technology Museum, Changchun 130000, China

*Corresponding author, Email: wyjs-107@163.com

Abstract

Modeling for wireless sensor networks is very challenging because the modeling needs to adapt network dynamics and find out multiple optimizing paths from the microscopic point of view. In this paper, we propose a cellular automata model that focuses on dynamic network topology, multipath data transmission mechanism and energy overhead. Each node in a network is represented by a cell, and any permutations and combinations that represent any links between two cells constitute the cellular space. A wireless sensor network is modeled by related cell states and cell evolution rule. A cell transmission model is derived for multipath transmission of information. All these aim to ensure network reliability with the minimum resource requirements. Presented analytical work is proved validly by simulations.

Keywords

Cellular Automata; Microscopic mode; Modeling; Wireless Sensor Networks.

1. Introduction

With rapid development of the Internet of Things (IOTs) [1], Wireless Sensor Networks (WSNs) [2] play an more and more pivotal role in bridging the gap between the physical and virtual worlds, which can enable things to respond to changes in their physical environment. Therefore, with WSNs technology improving, a new model that could adapt various application environments is needed to describe characteristics and goals of WSNs exactly. Concerning IOTs, the model must be applied to a wide range of WSNs.

Tarik *et al.*, [3] analyze some methods about WSNs modeling, and currently, these models have been explored with different features. It examines this emerging field to classify wireless micro-sensor networks according to different communication functions, data delivery models, and network dynamics. A service-centric model focuses on services provided by a WSN and views a WSN as a service provider [4]. The service-centric model only provides a holistic approach to measuring and presenting WSNs effectiveness. There is no description from the microscopic point of view in this model. The methodology for the modeling and the worst-case dimensioning of cluster-tree WSNs shows the fundamental performance limits of cluster-tree WSNs [5]. Although it presents a general and flexible framework, the node function in such model is hierarchical. The Cluster Head nodes that are used for transmitting data packets will consume more energy. Then nodes inequality will reduce the network life systematically. Yet some routing protocols use another model that is based on data-centric [6], and this model depends on data identifiers and specified locations, therefore, it isn’t appropriate to the dynamic and randomly-deployed WSNs, and it have no strong convergence.

Cellular automata (CA) is the dynamical system that evolves in the discrete time dimension according to some local rules, which is essentially defined in a cell space constituted of cells with discrete and finite state [7][8]. In this paper, a cellular automata modeling view is proposed for WSNs. Our basic goal and idea are to ensure WSNs continuing and effective work by using some simple parameters, connection and operation rules, and finally simulate complex and rich applications of WSNs.

2. Model for WSNs

WSNs have many challenges compared with traditional wireless networks, and communication in WSNs differs from that in other types of networks. More specifically, WSNs energy is often limited since it is impossible to recharge sensor nodes if the networks are deployed in the uninhabited areas. This paper uses the following models to evaluate the performance of WSNs, including the dynamic network topology and data transmission reliability, and finally realize energy saving and prolong networks lifetime, which could keep the model practicality and simplicity.

2.1 Network model

In order to describe the model better, the following definitions are given firstly.

Definition 1: The set of all the nodes C = {c1, c2, … , cn}, Then any permutations and combinations L in set C constitute the cellular space, where L = {Lk = (c1, … , ci, … , cj, … cn)| ci, cj∈C, ci≠cj, i, j = 1, 2, … , n, k∈Z}, and each node is a cell (The cellular space is a two-dimensional grid).

Definition 2: Let S represents limited and discrete states set of cells, where S = {s1, s2, s3}, s1: information transmission state, s2: wait state, s3: idle state, and three states represent three types of cells respectively: center cell(CC), neighbor cell(NC) and idle cell(IC).

Definition 3: Let N represents cell link neighborhood, where N = {Lk*|difference (Lk1 - Lk2)≤d, Lk1, Lk2∈Lk}, difference(Lk1 - Lk2) is the difference between two permutations and combinations, d is the degree of difference.

Based on above definitions, the paper uses the following rule to update model in parallel.

Rules $F : S_t \to S_{t+1}$:

Step 1: Initialize the parameters and define cell state,

C = {c1, c2, … , cn}, S = {s1, s2, s3}.

Step 2: Assuming that In is the number of idle cells, Nn is the number of neighbor cells, then determine the next hop link by judging the states of different types of cell.

Case (1): If CC has In idle cells (ICs) around(In≤6), it forwards the data packets to the next hop by cell transmission model(described in the next section), which uses an IC.

Case (2): If CC has no ICs but has Nn neighbor cell (NCs) around, it forwards the data packets to the next hop by cell transmission model, which uses a NC.

Case (3): If CC has no ICs and NCs around, that is, its neighbor cells are all in information transmission state, then this CC stores the data packets into the cache, and once it receives cell release message, it chooses this cell to forward the data packets.

Step 3: With the dynamic changes in topology, establish a number of transmission links, and use

N = {Lk*|difference(Lk1 - Lk2)≤d, Lk1, Lk2∈Lk}

to compare neighborhood of links, then choose the most effective link for related information transmission.

Step 4: Update link, store the multiple link information.

The network model is constructed by cellular automata. The aim of this cellular automata model is to group cell nodes that have similar processing needs into unit cell families and sink node that meet these needs into each cell in the network.

2.2 Cell transmission model

The following assumptions are adopted for simplifying the model:

Communication radius of the center cell (CC) is its six neighbor cells.

Except Sink cell, each cell has the same initial energy.

Communication is symmetric.

Each cell keeps static or movement according to the dynamic rate δ_n.

For facilitating the model description, we define the following variables:
fl :data frame length;
lc :channel length;
ve: transmission rate of electromagnetic waves in the channel;
vi(t) :data rate of the cell i at time t;
Di,j :time delay, from cell i to cell j;
Bi,j :highest data rate in unit time that could be reached from cell i to cell j;
qi,max(t) :max upstream data flow of the cell i at time t;
hi,j :hops, from cell i to cell j;
ni,j :the number of links, from cell i to cell j.

In order to describe flow relationship between CC and neighbor cells, firstly, the metrics delay that we consider mainly between two cells can be formulated as

$$D_{i,j} = d_t + d_p \tag{1}$$

where dt is transmission delay, dp is propagation delay. Typically, we have

$$d_t = f_l / v_i(t) \tag{2}$$

$$d_p = l_c / v_e \tag{3}$$

Secondly we consider another metrics delay-bandwidth product,

$$\tau = D_{i,j} \times B_{i,j} \tag{4}$$

It represents the number of bits that this cellular link could accommodate. Thirdly, the data flow direction is divided into upstream and downstream. Normally, most event-driven messages in WSNs are forwarded from individual cell to the sink in upstream direction, thus in this paper we focus on the max upstream data flow of cell i at time t, qi,max(t). Therefore, based on vi(t), τ and qi,max(t), we define maximum carrying capacity of cell i, Ni, and we have

$$N_i = balance\ \{ v_i(t), \tau , q_{i,max}(t)\} \tag{5}$$

Then each CC determines the next link by comparing Ni value among the neighbor cells.
We consider

$$Q_{i,j} = \sum_{i=1}^{h_{i,j}} N_i \tag{6}$$

it represents the total maximum carrying capacity of one link from cell i to cell j. Then the mean value of variable Ni can be calculated as

$$\vec{\mu} = E[\vec{N_i}] = (E[N_1], E[N_2], \cdots, E[N_{h_{i,j}}])^T \tag{7}$$

From (7), cell transmission equation of multipath selection is given by

$$P = \{max \overset{\rightarrow}{\mu}(n) \ (n \leq n_{i,j}), min\ h_{i,j} \} \qquad (8)$$

Given such a cell transmission model, we address multipath transmission of the information for WSNs compared with other forwarding strategy [9], and aim to ensure the network reliability with the minimum resource requirements.

3. Simulation Results

Setting 60 sensor nodes and a sink node in an area of 50m×50m to certify the effectiveness of the network model, the simulation setting parameters are shown as Table I. We use IEEE 802.15.4 as the Physical layer and Data link layer protocol. The maximum datagram size of each cell is 127-bytes.The maximum transmission distance that cells can be reached is 12m, and the network range is 50m×50m.In addition, data flow style is CBR.

Table 1 Simulation Parameters

Parameters	Set Value
PHY/MAC	IEEE 802.15.4
Maximum Datagram Size	127 bytes
Max Transmission distance	12m
Network Range	50m×50m
Data Flow	CBR, 100bytes

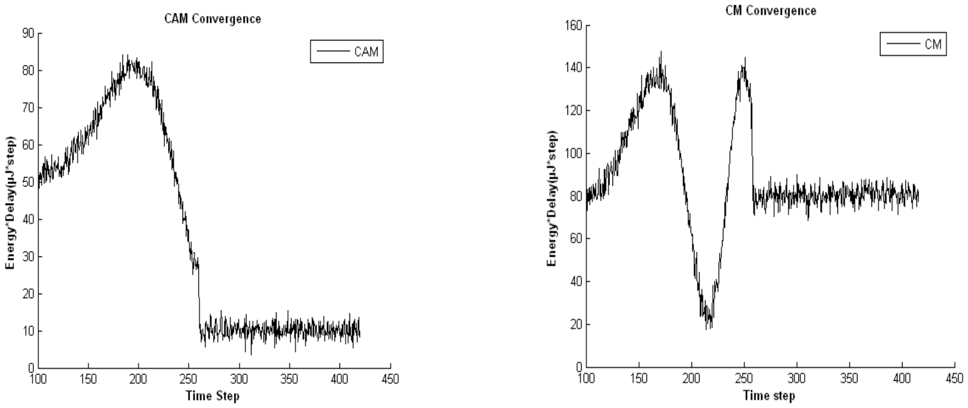
The simulation results is verified by three models, which is including service-centric model (SCM) [4], cluster model (CM) [5], and our cellular automata model (CAM). SCM focuses on services provided by a WSN and views a WSN as a service provider. A WSN is modeled at different levels of abstraction. For each level, a set of services and a set of metrics are defined. Services and their interfaces are defined in a formal way to facilitate automatic composition of services, and enable interoperability and multitasking of WSNs at the different levels. CM provide a fine model of the worst-case cluster-tree topology characterized by its depth, the maximum number of child routers and the maximum number of child nodes for each parent router.

The first experiment is the comparison of models convergence. We apply the classical LEACH (Low Energy Adaptive Clustering Hierarchy) [10] protocol to CM and CAM. Fig. 5 shows the simulation result of convergence, which is measured by the metrics of Energy*Delay [11] with changing of time step. Energy*Delay model, introduces a great energy-effective solution to the communication from source nodes to destination nodes and significantly simplifies the topology of networks. From the research and simulation results that described in [11], a significant effect on determining the increment of pheromones by minimizing the Energy*Delay model was obtained.

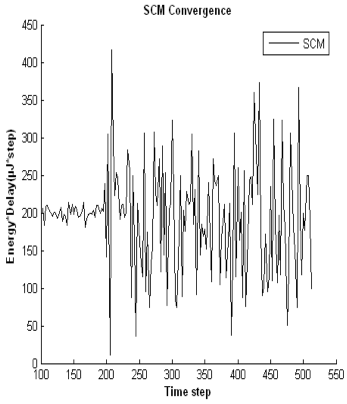
In the initial stage, there is a huge fluctuation about the metrics of Energy*Delay in the CAM, CM and SCM, this because the initiation of cellular automata. After such processing, the Energy*Delay tends to a fixed value. As shown in Fig. 5 (a) and (b), CAM gradually converges to 10, however, CM gradually converge to 80. In addition, as we known that, SCM is a macro-model, then from Fig. 5 (c), we can find that SCM has a huge fluctuation almost all the time by the metrics of Energy*Delay, so it has the worst convergence during three models. Therefore, it is concluded that CAM that use cellular automata scheme has better convergence performance than CM and SCM.

Secondly, we simulate the network on different models for comparing the number of paths between two cells. From Fig. 6, CAM takes less time to forward the data packets through the network than the other two models. The reason is that CAM has the characteristic of multi-path transmission by cells auto selection method. And as shown in Fig. 6, although CAM finds less paths in local time slot, the tendency of finding more paths about CAM is increasing step by step compared with the other two models.

Finally, Fig. 7 presents the overhead results of the three models in dynamic environment described in Section II. A global analysis shows that CAM gives the best performance with the increasing of the dynamic rate δ_n , which is almost independent of δ_n . This is because that CAM uses the cellular evolution rules to optimize the network formation process, and decrease the number of messages exchange.



(a) CAM Convergence (b) CM Convergence



(C) SCM Convergence

Figure. 5 Convergence comparison

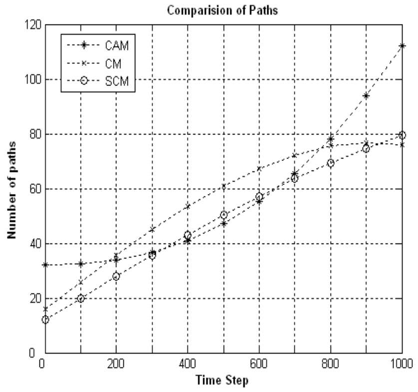


Figure. 6 Paths Comparison of Models

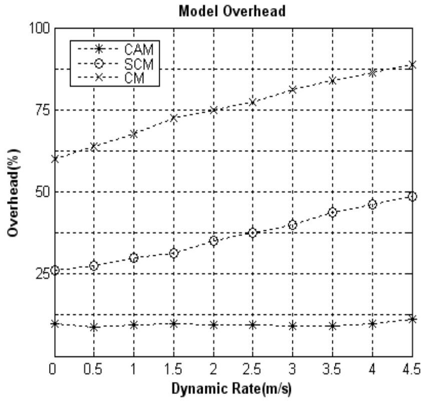


Figure. 7 Overhead Comparison of Models

4. Conclusion and Future Work

In this paper, a cellular automata model is devised for WSNs application research. The key issues considered in this model are dynamic network topology structure, multipath data transmission, and WSNs network energy efficient. Simulation results by the comparison of convergence, multi-path transmission and overhead, verify the effectiveness of the related work.

However, there are much uncertainty for popularization of the IOTs, and many technical aspects based on WSNs that need to be broken through [12]. In the future work, we plan to apply this model to research WSNs routing algorithm and time synchronization strategy for solving WSNs localization problems [13] [14]. Moreover, these researches will provide a foundation that achieves the integration between WSNs and Internet of things.

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WANG Yijun, he has been with the Changchun University of Science and Technology, China, where he is the lecturer of wireless communication in the School of Electronic and Information Engineering. Dr. Wang’s research interests in wireless communications and signal processing. Email: wyjs-107@163.com.