

Interconnecting Containers by Wireless Sensor Network

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Abstract. Container transportation is the prevailing international cargo transportation method. However there is no way to monitor the freight status inside as the containers are made of steel. A feasible monitoring method is very important, especially for special cargos such as dangerous goods. This paper proposes a scheme to form a network of intelligent containers based on wireless sensor network. A specialized routing algorithm is also proposed to meet the characteristics container network. Simulation results shows that the proposed networking scheme can make solid communicating infrastructure for upper layer container monitoring services.

Keywords: Container; Container Network; Wireless Sensor Network;

1 Introduction

With the advent of economic globalization, more than 200,000 standard containers have been used in the global trade, and now they have bear 90% of world trade transportation. However, since 9/11, the attention on the international container transport security keeps constantly rising. During the transport process, container is an opaque "black box". Outside world cannot know whether its internal cargo is safe. A lot of new worldwide regulations and initiatives had been introduced in the container safety [1], but there is still no effective preventive measure. In the field of Container tracking and positioning, RFID-based electronic tagging system has been used [4]. Comparing with other solutions, container positioning and tracking system which based on RFID is simple to deploy, and convenient to conduct positioning, but still has many shortcomings. Tags can't compose a network because installing electronic tags on containers can only passively read and these tags cannot communicate with each others. Beside this, RFID readers can only be deployed at some special locations such as port gate etc.

Therefore, building a container positioning system based on wireless sensor network is a nature choice. The flexible deployment, without infrastructure, longer communication distance and the real-time accurate positioning are all WSN's advantages. However, there are two technology problems hinder the application of WSN to container monitoring and tracking. The first one is communication shadow

which is brought by the stacked containers. And the second one is energy consumption issues which are introduced by traditional WSN communication methods. This paper proposes a scheme to interconnect containers and makes them a network infrastructure for upper layer applications. The rest of this paper has been organized as follows. In Section 2, we present the container interconnection scheme. In Section 3, we present some experiments results. Concluding remarks are included in Section 4.

2 Interconnecting containers

2.1 Networking scheme for stacked containers

1) Communicating between containers:

As shown in Fig 1, each container will be equipped five wireless nodes with low power consumption hardware. All these five wireless nodes have a container identify number (Container ID) and a deployment position number (Position ID). The former is used to get the exact position of unique subsidiary of the container. The latter denotes the position of these nodes when mounted on the inside wall by hard wiring. The communication range of all of these nodes is limited to a quite small distance (say 0.8 meter), so that only when a container is close to another one, there can be a connection between them being set up. After one wireless node sets up connection with another one, they will both know that there exists another container and then collaborate to establish communicating link, thus form a small intelligent container network. In addition, according to the locations of wireless nodes on the containers that having link to each other, relative coordinates between the two containers will be assigned. As shown in Fig 1, if node 1 of container A is connected with the node 5 of container B, then after establishing a connection, we can determine that the container B is stacked on the top of the container A, thus the relative coordinates of these two containers can be obtained. If node 5 of the container A has not established a connection with any other nodes, it can be inferred that the container A is at bottom layer, thus the absolute coordinates of the containers can be obtained accordingly.

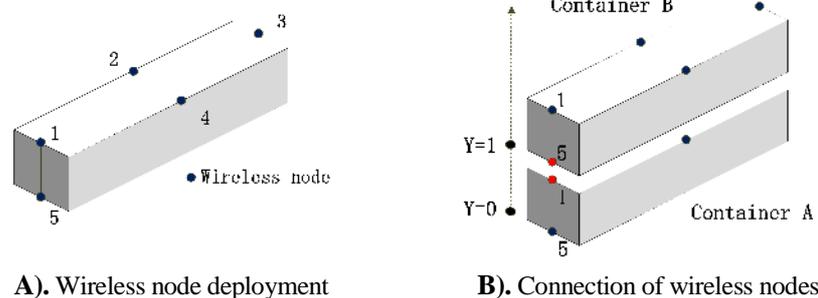
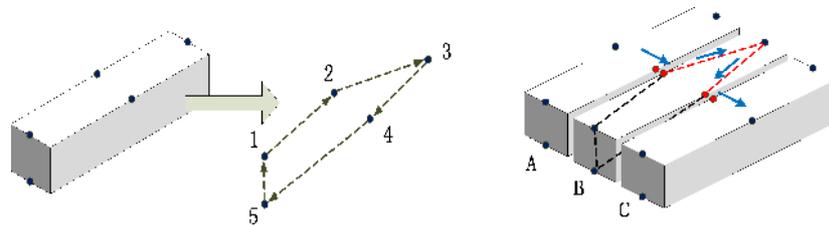


Fig.1. Communicating between two containers

Similarly, as long as there is a new incoming container being stacked onto the existing container network, the container network will grow automatically and the addressing system will refresh all nodes' coordinates and all containers' relative positions.

2) Communication inside a container

As shown in Fig 2, each container will deploy 5 wireless nodes. Cables such as USB cable can be used to form a ring of nodes in the interior wall side of the container. Data transmission among the nodes takes a sequential ring communication way. Thus the routing table is static, and the packet routing path would be from node 1, to node 2, until to node 5. If a node receives data packet, it should first use dimensional order routing (DOR) to determine the next hop container, so that it can obtain the Position ID of the destination node in this inner container transmission. Then, it compares its own Position ID with Position ID of this inner container destination node. If not, then it transmits the packet in a clockwise manner. This transmission will keep going on until the inner container destination node is reached. Then the data packet is transfer to the exterior side to be sent to node of next hop container. For instance, as shown in Fig 2(B), container A needs to send a packet to container C. Packets is sent from node 4 of container A to the node 2 of container B, then it gets entered into the box of container B. Node 2 of container B uses DOR to find the next hop is the container C on the right side, therefore the inner container destination node is node 4. Thus, the packet takes a clockwise loop through node 3, and reaches node 4. Once node 4 receives the packet, it uses the external wireless link to send the packet to the node 2 of container C.



A). Ring route inside a container B). Packet transportation between 2 containers

Fig.2. Communicating inside a container

2.2 Routing method

In order to make the container network feasible in real world applications, low-energy consumption, low-latency communicating method has to be designed for this wireless sensor network with 3D mesh topology. Traditional routing methods such as AODV and DSR etc don't seem to be good choice here as they are energy demanding and require unnecessary communication overhead due to regular broadcasting or route discovery. In this article, we proposed a novel simple dimensional ordered routing method, SDOR. The purpose of this algorithm is two folded. One is to explore the characteristics of the stacked containers and then find the shortest route that can delivery packet from a container to the target node, the other is to save energy of all

the communication nodes in the whole network. We will introduce them respectively in the follows. As five wireless nodes are deployed in each container, they all have identical Container ID. In addition, they are interconnected with hard wire. Therefore, in the routing algorithm description, they can be abstracted as one node set. Each node set maintains a state table of its adjacent node position as follows:

Struct LocationStatusTable

```
{
  bool UpLinked;
  bool DownLinked;
  bool LeftLinked;
  bool RightLinked;
  bool BehindLinked;
  bool FrontLinked;
}
```

SDOR relies on querying the status table of adjacent node to determine next hop node, the algorithm definition is as follows:

$$R_{x-y-z}(N_{xyz}) = \begin{cases} N_{(x-1)y} & \text{if } N_{xy} \text{ LeftLinked} \wedge D_i x < N_{xy} x \\ N_{x(y-1)z} & \text{elseif } N_{xy} \text{ FrontLinked} \wedge D_i y < N_{xy} y \\ N_{xy(z-1)} & \text{elseif } N_{xy} \text{ DownLinked} \wedge D_i z < N_{xy} z \\ N_{(x+1)y} & \text{if } N_{xy} \text{ RightLinked} \wedge D_i x > N_{xy} x \\ N_{x(y+1)z} & \text{elseif } ((N_{xy} \text{ BehindLinked} \wedge D_i y > N_{xy} y) \\ N_{xy(z+1)} & \text{elseif } N_{xy} \text{ UpLinked} \wedge D_i z > N_{xy} z \end{cases}$$

Where R is routing function, N_i is node-set, S_i is source node set, D_i is target node set, x is the coordinate at x-axis, y is the coordinate at y-axis, and z is the coordinates at z-axis. So the SDOR will route the packet sent from a container following the sequence of x-axis, y-axis and z-axis until it reaches the target node which usually is the container with coordinate (0,0,0) and can behave as a gateway to communicate with access point of other existing network.

It can be learned from the simulations that the dimensional ordered routing algorithm presented above has a good performance in terms of average energy consumption and average packet delay. However, the energy consumption at bottleneck link nodes is much higher than other nodes. We define the bottleneck link nodes as the nodes that form the communicating route of the packets at its layer. The network can get paralyzed because the bottleneck link nodes run out of energy much quicker than others. To avoid this situation, SDOR conducts a dimensionally scan to balance the usage of all the nodes in network. That is, based on the dimensional ordered algorithm described above, SDOR sets an energy consumption threshold at each bottleneck link node, say 10% of initial energy. Once energy consumption of any node on the bottleneck link exceeds 10%, this node will initiate a broadcast in the whole network which announces that the bottleneck link is shifted one unit toward a specified direction. Then when source nodes send packet after knowing this

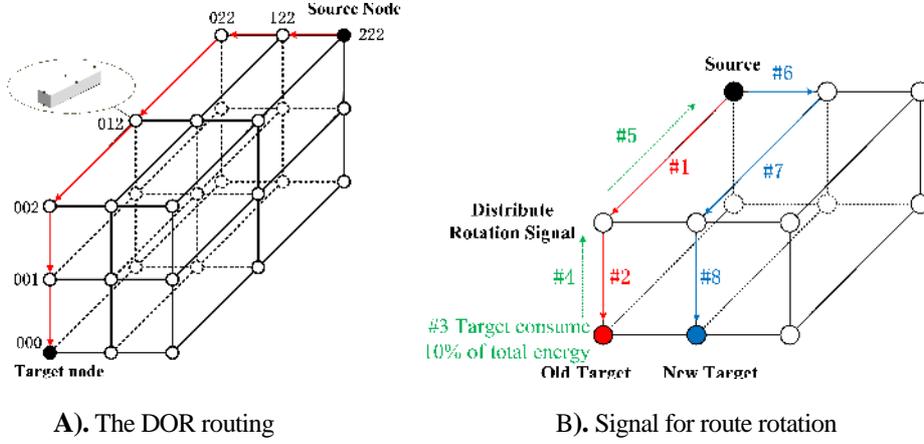


Fig.3. SDOR routing method

announcement, the route will be a new one. This process is shown in Fig 3(B). We call this process as energy consumption rotation. The rotation is conducted on a specified plane, thus the energy consumption of every link on this plane is in a cyclic way. Therefore, the energy consumption formerly on one dimension is now distributed to two dimensions, which makes the entire network survive longer.

3 Simulation Results

3.1 Simulation configurations and the simulated metrics.

Simulations are carried out on an open source WSN simulator. We simulated two 3D meshes which are at scales of $3*5*7$ nodes and $4*6*8$ nodes respectively. Each node only connects to its neighboring nodes with duplex channel. In the simulation experiments, every 0.5 second s a node is randomly picked to send a message to the target. As we don't let any node run out of energy, thus the simulation results of DOR and SDOR will be same. Therefore, we fix the target node at (0,0,0) to simplify the simulation settings. Each data packets are in 3 sizes which are 250bit, 500bit and 1000bit respectively. The initial energy for each node is 1000unit.

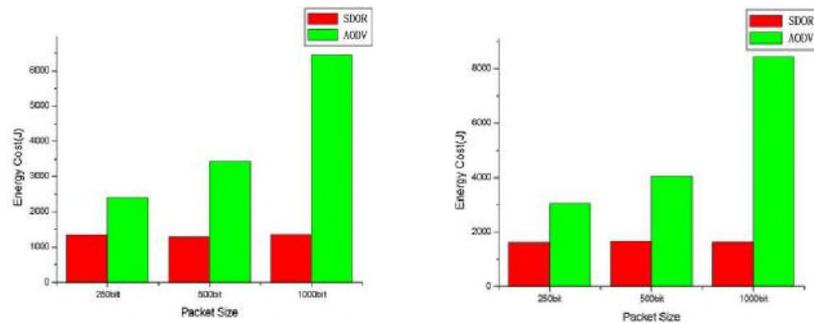
Other pertinent settings are as the follows. Sending one packet costs 1 unit energy; receiving one packet costs 1 unit; sleeping for a cycle costs 0.001 unit; and the transmission delay between two nodes are 10ms. When the target node receives the 100th packets, we record the remaining energy of all the nodes in the network. The metrics we examined in the experiments are average delay $Delay_{avg}$ and energy consumption EC which are defined as follows:

$$Delay_{avg} = \frac{\sum_{i=0}^{n-1} Delay_i}{Num} \quad , \quad Delay_i = T_{recv_i} - T_{send_i} \quad (1)$$

$$EC = \sum (E_{totalInit} - E_{totalFin}) \quad (2)$$

3.2 Simulation results

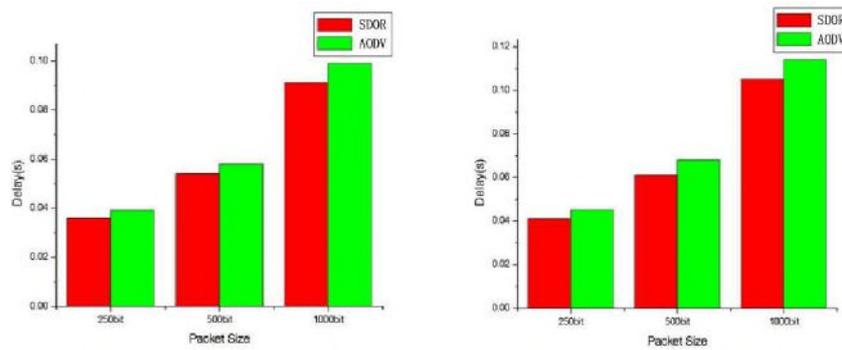
We compare SDOR with AODV to evaluate its performance. The performance comparison results in terms of cumulated energy consumption and average packets delay is shown in Fig 4 and Fig 5 respectively. We can see that SDOR is much better than AODV in terms of energy consumption, and it's also slightly better than ADOV in the message delay comparison.



A). 3*5*7 nodes container network

B). 4*6*8 nodes container network

Fig.4. SDOR v.s AODV on energy consumption



A). 3*5*7 nodes container network

B). 4*6*8 nodes container network

Fig.5. SDOR v.s AODV on average message delay

4 Conclusions and Future Work

This paper proposes a novel interconnection scheme to form a special 3D dimensional network which is composed of intelligent containers based on wireless sensor network. A specialized routing algorithm SDOR is also proposed to meet the characteristics container network. Simulation results shows that the proposed networking scheme can make solid communicating infrastructure for upper layer container monitoring services. In the future we'll keep on researching how to implement the scheme into real application which can continuously monitor internal status of the steel made containers.

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