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Comparison and Performance Evaluation of Routing Algorithms between Wireless Sensor Networks and Interconnection Networks

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Abstract

The routing algorithm is one of key researches of interconnection networks and wireless sensor networks (WSN) design. A routing algorithm defines a route which packet traverses to get to destination. In this paper we study some kinds of routing algorithms which are used in interconnection networks and wireless sensor networks separately. First, we demonstrate routing algorithms in WSN in different groups of flat routing, hierarchical and position based algorithms. Afterwards, we study adaptive and deterministic routing algorithms and express circular model (turn model) applying in internal connections networks. We compare and evaluate the performance of discussed algorithms. Finally by combining these protocols, we will demonstrate similarities and differences from different aspects.

Key words: Interconnection networks, Routing, Routing protocols, Wireless Sensor Networks.

1. Introduction

In the recent decade, the improvement of technology in transmission and electronic components has led to production of tiny and comparatively cheap microprocessors which are connected through a wireless network. On the other hand, taking advantage of integrated circuits by integration of transistors and the regular substructure base design, has propound network on chip architecture to achieve higher flexibility and assured implementation.

With attention to the importance of sensor networks utilization in time sensitive applications and the new connective technology being implemented on a chip in order to prepare a structured and standard connection between resources and different IP Core blocks, motivated us to investigate WSN and NoC routing protocols and their specific characteristics.

In this paper we will investigate and compare routing algorithms in these technologies based on modules connectivity and data transmission method, energy consumption and target investigation. In section two and three, WSN and NoC routing protocols will be illustrated and in section four, we will consider the performance evaluation of propound protocols.

2. Wireless Sensor Network Routing Algorithms

Routing protocols, based on network structure are divided into Flat, Hierarchical and Location-based protocols. In Flat routing algorithms, sensor nodes have similar functionality in data gathering, transmission and power consumption. In Hierarchical routing algorithms, nodes are divided into several clusters and commonly in each cluster, the node with higher energy level, is selected as the cluster head. In Location-based routing algorithms, sensors use geographical information to send data to specified regions.

2.1. Flat Routing Protocols

Flat routing protocols are divided into below categories:

- SPIN: SPIN adaptive protocol is presented in [1] which uses negotiation and resource adaptation to recover flooding method's deficiencies. In this protocol, each node send a Metadata which present attributes of main information and negotiate them with other nodes. By using this method, no additive information will be transferred in network.
- SPIN functionality is divided into three steps: Advertise new data, Request for data and Sending actual data. When a sensor receives new data from environment, it sends an ADV message to its neighbors. Afterwards if the neighbors require these data, they will send REQ message and finally main data will be sent to them.
- Directed Diffusion: SPIN method is commonly used for low data transfer rate but if there is necessity to send data periodically and constantly to the main station, Directed Diffusion Protocol [2] is used with higher performance and functionality. In this method, the sink which is interested in receiving messages, flood the interest message in network. Each node which receives the interest message from the neighbor node, keeps it in an interest cache table. Each message has a gradient which refers to number of times it has been received from neighbor nodes. In the next step, interests with their gradients are sent to other neighborhoods. By investigating the interest cache, the source node which is the information producer, send the required information to interested neighbor nodes. Finally, the requisite data which is produced by source is received by sink. The sink node sends a positive reinforcement message on the path which data has been received to amplify it. With this manner, a path is created between source and destination.

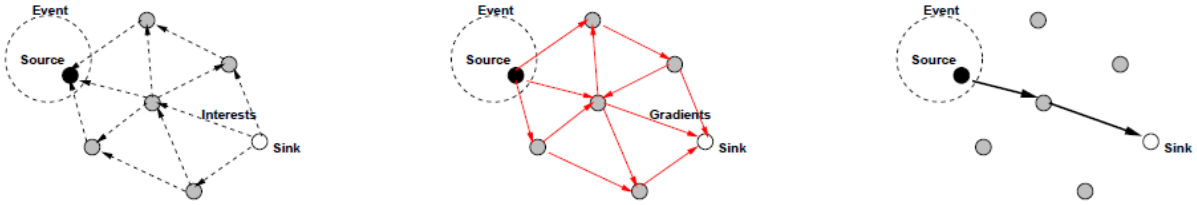

Fig 1: Directed Diffusion Protocols

- Rumor Routing [3]: this protocol is derived from directed diffusion protocol and is candidate for applications with impossible geographic routing. In this protocol, requests are sent to the nodes which have sensed a specific event, instead of flooding them in the whole network.

2.2. Hierarchical Routing Algorithms [4]

Hierarchical routing protocols are distributed into below categories:

- LEACH: LEACH as the first propound protocol in clustering in WSN, has used the idea of Rotational Clustering Method. In this protocol, by supposing a network with N nodes and K cluster heads (CH), with probability of Pi(t) each node will introduce itself as CH in each round. This probability is assigned in the way that the expected value for each cluster head is K (illustrated in equition1):

$$\mathrm{E}[\#CH] = \sum_{i=1}^{N} P_i(t) \times 1 = K \quad (1)$$

After selecting the CHs, They send advertisement messages with CSMA protocol. These messages should be extended in the manner that each node in network receives at least, one advertisement message. By receiving the strongest advertisement message other nodes will join to its cluster.

In the next step, CHs prepare a TDMA scheduling program to manage data transfer from cluster member nodes. This will prevent from data collision and will also reduce energy consumption. Finally, by receiving TDMA scheduling program in cluster nodes, Steady State Phase will start. In this phase nodes send their specific data to CH and CHs receive, aggregate and finally send them to the destination.

- PEGASIS this protocol is presented to improve LEACH protocol [5]. In this protocol just one node has direct connection to the Sink and the other nodes should be connected to the most nearest node to receive required data. Then it aggregates this information with its own data and extracts a packet and it is sent to the nearest node on the path. The path selection is done using Greedy algorithm and is started from Sink. Generally, data fusion reduces the transmitted data from source to destination. When 1% to 100% of nodes are dead, this protocol has 100% to 300% improvement in comparison with LEACH.
- TEEN: TEEN protocol is designed to prevent unexpected alterations in environmental parameters. This capability is so important in time sensitive applications, especially in reaction operation networks. TEEN follows data centered model and after clusters creation, CHs send two soft and hard threshold levels to their member nodes which are used to receive data. These threshold levels are used to activate nodes in different conditions and will change node status to transfer state.

2.3. Location-based Protocols

These protocols are divided into below categories:

- GAF: this protocol divide network to virtual grids and in each grid, nodes run different rules cooperatively. For example grid nodes activate a node for a specific period of time and sleep themselves. This node is responsible to monitor and report network activities to the sink. Each node by using GPS, present its position in virtual grid. So GAF saves energy and increases network life time by turning off the unnecessary nodes in network.

  The main point in GAF is to select cell dimension in grid in a manner that nodes can coordinate with their neighbor nodes. So if r is the side of each cell, R is the maximum distance between two cells in two neighbor nodes, there will be a right triangle which one of its sides is r, the other side is 2r and its hypotenuse is equal with R (illustrated in figure2). Then:

$$(2r)^2 + r^2 \leq R^2 \Longrightarrow 5r^2 \leq R^2 \Longrightarrow r \leq \frac{R}{\sqrt{5}} \quad (2)$$

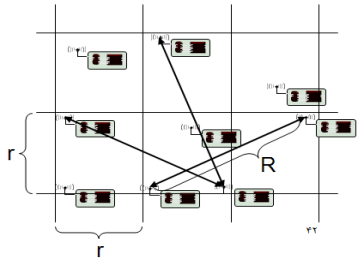

Fig 2: Size of each Cell in GAF

- GEAR: This protocol use geographic information to send requests to required regions. The main idea is to send interest messages of Directed Diffusion to specific regions instead of whole network. By reducing the number of messages, it saves energy in Directed Diffusion protocol.

3. NoC Routing Protocols

Many properties of the interconnection network are a direct consequence of the routing algorithm used. Among these properties we can cite the following:

- Connectivity: Ability to route packets from any source node to any destination node.
- Adaptively: Ability to route packets through alternative paths in the presence of contention or faulty components.
- Deadlock and live lock freedom: Ability to guarantee that packets will not block or wander across the network for ever.
- Fault tolerance: Ability to route packets in the presence of faulty components. Fault tolerance can be achieved without adaptive ness by routing a packet in two or more phases, storing it in some intermediate nodes.

NoC routing algorithms are classified based on many parameters. These parameters are differenced from many aspects such as number of destinations, routing decision, implementation, packet sending method from different paths, progressiveness and number of paths [6]. The most important classification in NoC is based on deterministic and adaptive routing. Deterministic routing algorithms always supply the same path between a given source/destination pair. Adaptive routing algorithms use information about network traffic and/or channel status to avoid congested or faulty regions of the network.

3.1. Deterministic Routing Algorithm

Deterministic routing is distinguished from oblivious routing. Deterministic routing algorithms establish the path as a function of the destination address, always supplying the same path between every pair of nodes. This algorithm routs flits in X direction and then routs it in direction of Y to reach to destination. This algorithm is called XY algorithm. In this method if a link is occupied with a flit, flits should be blocked until the path is released. This is the algorithm's weak point. The strength point of this algorithm is simple implementation and deadlock-free.

3.2. Adaptive Routing Algorithms

- West-First Routing Algorithm: in this method for optimized routing, if destination is located in right or east, it behaves adaptive, otherwise it behaves deterministic. It route a packet first west, if necessary, and then adaptively south, east, and north. In other words, if the source point in X axis is X_s and the destination point in X axis is X_t; if $X_s \leq X_t$ then destination is on the west and routing would be deterministic. Else if $X_s \geq X_t$ then destination would be on the east and routing would be adaptive. If non optimized routing is legal, adaptive routing is done approximately.

This algorithm has limitations to avoid deadlock. Figure 3 illustrate these limitations.

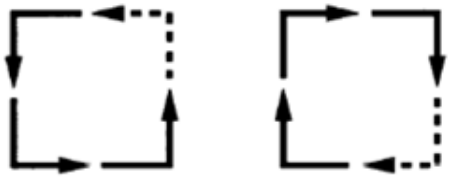

Fig 3: West-First Algorithm's turn Limitations

- North-Last Algorithm: for optimize routing in this algorithm, if destination is located in the south of starting point, it would be adaptive, and otherwise it would be deterministic. In other words, if the source point in Y axis is Y_s and the destination point in Y axis is Y_t; if $Y_s \leq Y_t$ then destination is on the north and routing would be deterministic. Else if $Y_s \geq Y_t$ then destination would be on the north and routing would be adaptive. This algorithm has limitations to avoid deadlock. Figure 4 illustrate these limitations.

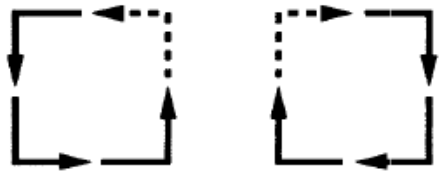

Fig 4: North-Last Algorithm's turn Limitations

- Odd-Even Routing Algorithm: this protocol has limitations to prevent deadlock and simply prevents deadlock in 2D mesh topology without having virtual channel. In this algorithm a column is called even if X value is even and the column is called odd if the X value is odd. The rotations contain -90 to 90 degree. This algorithm contains eight kind of rotation. A rotation is defined ES if we move from east to north. Seven other rotations are defined also the same and are called: NE,SW,SE,WN,WS,EN and NW. this algorithm contains two main rules:
  - Each packet is not allowed to do an EN turn, if it is located in an even column. Also each packet is not allowed to do an NW turn, if it is located in an odd column.
  - Each packet is not allowed to do an ES turn, if it is located in an even column. Also each packet is not allowed to do an SW turn, if it is located in an odd column.

The Odd-Even algorithm has less complexity in comparison with XY algorithm and can define many paths from a source to a destination. Also it is deadlock-free.

4. Results and Analysis

In this chapter we evaluate and compare the performance of discussed algorithms above. Afterwards we combine wireless sensor networks and network on chip protocols and will demonstrate similarities and differences from different aspects.

4.1. Evaluation of Flat Network Protocols

In this section we evaluate and compare main protocols in flat Networks. As mentioned before, Directed Diffusion is the most powerful data-centric protocol but it uses flooding to send interest message. Therefore Rumor Routing protocol is used to solve the problem of flood message sending in Directed Diffusion; most protocols in this field are derived from Directed Diffusion and have better mechanisms in some conditions. In Table 4-1, we have compared SPIN, Rumor Routing and Direct Diffusion Protocol.

	SPIN	Directed Diffusion	Rumor Routing
Working Mode	Flat	Flat	Flat
Send/Receive Messages	Too many	many	Few
Knowledge of Neighbor Node Position	No	No	No
Verification with Dynamic Environment	Yes	Almost	A little bit
Negotiation	Yes	Yes	Yes
Send Meta-Data	No	No	No
Memory Requisite for each node	Almost high	Almost high	Proportional with Events Ratio
Processing Rate	Low	Low	Proportional with Events Ratio
Robustness	Low	High	Low
QoS	No	No	No

Table4.1. Comparison between SPIN, Directed Diffusion, Rumor Routing Protocols

4.2. Evaluation of Hierarchical Network Protocols

LEACH is one of the fundamental and powerful routing protocols which are designed for hierarchical networks; but LEACH weak points led to the design of other protocols such as PEGASIS. However PEGASIS increases network life time and decreases overhead on CHs, but it needs to keep the information of neighbored nodes and it leads to network overhead. TEEN is a protocol which uses hierarchical and cluster structure ideas to optimize network parameters.
Table 4-2, illustrates the comparison between LEACH, PEGASIS and TEEN Protocols.

	LEACH	PEGASIS	TEEN
Working Mode	Hieratical	Hieratical	Hieratical
Use Specified path	Yes	Yes	Yes
Mobile Base Station	No	No	No
Network Lifetime	High	Very High	High
Negotiation	No	No	No
Use Meta-Data	No	No	No
Aggregation	Yes	No	Yes
Improve Routing	No	No	No
QoS	No	No	No
Power Consumption	High	High	High

Table4.2.Comparison between LEACH,PEGASIS and TEEN Protocols

4.3. Evaluation of Location-based Protocols

Several position protocols are designed for Ad-Hoc networks. These protocols have been designed based on sufficient energy in nodes. Generally each node needs specific modules such as GPS to be aware of its position, although using these modules have great cost and sufficient energy for calculation.
Because of limitation of energy resources in WSN, Ad-Hoc protocols are not so efficient in these environments; however protocols like GAF and GEAR are sometimes useful. Table 4-3 compares the characteristics of these two protocols.

	GAF	GEAR
Knowledge of Neighbor Node Position	Yes	Yes
Negotiation	No	No
Use Meta-Data	No	No
Transmitting More Information	No	Yes

Scalability	Properly	Limited
Need memory for each node	Low	Low
Processing Rate	Low	Low
Power Consumption	Limited	Limited

Table4.3.Comparison between GEAR and GAF Protocols

4.4. Evaluation of Network on Chip Protocols

Protocols which are used in NOC have basic differences with WSN protocols; however there seem some similarities and same characteristics. Deadlock detection is an important in NOC networks however this parameter is not propound in Sensor networks. On the other hand the power consumption and the optimized routing method are too important in both networks. In table 4-4 we have consider and compared NOC protocols.

	XY	WF	NL	OE
Type	Deterministic	Adaptive	Adaptive	Adaptive
No of Routing Path between Source and Destination	One route	One route	One route	Multi Route
Algorithm complexity	Low	Almost high	Almost high	High
Deadlock Free	No	Yes (using rotation limitations)	Yes (using rotation limitations)	Yes (using rotation limitations)
Back Tracking	No	Yes	Yes	Yes
Hardware Implementation	Simple	Complex	Complex	Complex
Improve Routing	No	Yes	Yes	Yes
QoS	No	No	No	No
Power Consumption	Low	High	High	High

Table4.4.Comparison between NOC Protocols

4.5. Differences and Similar Characteristics of WSN and NOC Networks

One of the parameters which is studied and analyzed in WSN and NOC networks is the number of modules and the interconnection between network components. The number of components in NOC is much fewer than the number of modules which are used in WSN.

The other main factor which is discussed in both WSN and NOC is power consumption. In NOC the increase of power consumption leads to the increase of temperature in network components; where this factor decreases the profitable network life time in WSN. In NOC the distance between components are static and is determined at the design time; but in WSN, the distance between nodes are dynamic and their topology could be changed due to environment conditions.

Table 4-5 illustrate differences between wireless sensor networks and network on chip [7].

	WSN	NoC
Communication Modules	Sensor Nodes	Specific Hardware Components
Links	Wireless (Single and Multi Hop)	Wired Routes and communication links are in Chip (Static Network)
Number of modules	Mean to High	Low to Mean (Determined in Design time)
Type of links	Loosely couple	Tightly Couple
Energy Awareness	Very Important (example: go to the sleep idle nodes)	Important (example: go to the sleep idle nodes)

Energy Awareness Routing	Yes (Location and Distance is important)	Yes (Influence on Reliability and Performance)
Using Switch	No	Yes
Topology	Dynamic	Static
Topology Control	By ON/OFF Nodes Connect/Disconnect Links	Static
Maintenance and Testability Properties	Too Complex (Nodes are Often Usable just Once)	Using Testability Mechanism
Applications	Dependent to application	Often public
Aggregation	Yes	No

Table4.5.Comparison between NOC and WSN

Although these networks have different characteristics but they have used each other's technology for their structure base. For example in [8] NoC technology is used for wireless sensor networks and in [9] sensors are used for NOC technology.

Collectively, the effective factors and base challenges in WSN and NOC are node deployment and IP Cores, Energy consumption, Node/link heterogeneity, Fault tolerance, Life time, Extensibility, Network Dynamics, Transmission media, Data Aggregation, Quality of Service, Maintainability and Resource Limitation. Although the role of each of challenges are different in these networks and may differ from condition to condition.

5. Conclusions

The flexibility, fault tolerance, high sensing fidelity, low cost and rapid deployment characteristics of WSN create many new application areas for remote sensing which would make senor networks an integral part of our lives in recent future. On the other hand, the routing algorithms are one of the most important researches of NoC design. This paper investigates and compares routing algorithms in WSN and NoC networks. WSN routing protocols are divided into Flat, Hierarchical and Location-based protocols. NoC protocols are evaluated based on many aspects. The most important classification is based on adaptive and deterministic routing.

WSN and NoC routing algorithms differences and similarities have been evaluated and compared in chapter 4 based on performances, QoS, algorithm complexity and etc. The similarity in both WSN and NoC is the numerous numbers of modules and the interconnection between network components. Energy consumption causes temperature increment in NoC where this parameter decreases network life time in WSN. Network traffic is much higher in WSN and topology control is static. WSN is generally application based and the nodes cannot be recharged or repaired most of the times.

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