Topologies and Metrics Relevant for Wireless Sensor Networks

Dr. Venkata Surya Narayana T

Associate Professor,ECM Dept,K.L University,Guntur.

Abstract:In this paper, A review of wireless data networks will be introduced. I will consider the physical arrangement which is used to interconnect nodes, that is known as the network topology and the process of determining a path between any two nodes over which traffic can pass which is called routing. Next is the switching techniques used in this work, which refers to the transfer method of how data is forwarded from the source to the destination in a network. In addition I will address medium access control protocols for wireless network system. And finally channel assignment strategies and wireless channel models will be reviewed.

Key words: WSNs,WMNs, MANETs,VANETs, Ad-hoc Networks.

INTRODUCTION:

Wireless networks, also called ad-hoc networks, formed by collections of wireless nodes communicating with one another with no pre-existing infrastructure in place; therefore, they are also called infrastructure less networks. A wireless network is ad-hoc if each node forwards data from other nodes and produces and consumes data of its own. Wireless ad-hoc networks have been the focus of much recent research, and include Mobile Ad-hoc networks (MANETs), Wireless Sensor Networks (WSNs), Wireless Mesh Networks (WMNs), and Vehicular ad-hoc Networks (VANETs).

An infrastructure less network can be either a single hop or a multi-hop network which autonomously operates in an ad-hoc mode without a central controller. The term multi-hop refers to the fact that data from the source needs to travel through several other intermediate nodes before it reaches the destination. Ad-hoc networks based on wireless technologies, such as IEEE 802.11 standard, which covers the physical and data link layers and mostly utilize a single radio and a single shared channel. As such, the bandwidth is divided between the nodes trying to communicate. One common problem with such protocols is that the network performance will degrade quickly as the number of nodes increases, due to higher contention/collision. On the other hand, the wireless standards IEEE 802.11a/b/g and IEEE 802.15.4, offer up to 16 non-overlapping frequency channels for simultaneous communication. These multiple channels have been utilized in infrastructure-based networks by assigning different channels to adjacent access points, thereby minimizing interference between access points. However, multi-hop wireless networks have typically used a single channel to avoid the need for co-ordination between adjacent pair of nodes, which is necessary in a multi-channel network. Multiple channels, however, partition the network based on the channel used. This may result in a disconnected network if the nodes communicate only in their assigned channels. To resolve this problem, several multi-channel ad-hoc/mesh network approaches have been proposed in the literature [2, 1]. Furthermore, Some research [2, 3] has been done on routing schemes in multichannel networks where the topology discovery and routing are performed with a channel assignment. In addition, they are considered these issues as separate problems thus reducing complexity of the schemes. So et al. [2] have proposed a routing protocol for multi-channel networks that uses a single interface at each node, while our proposed solution works with multiple radio interfaces per node. Raniwala et al. [2] propose routing and interface assignment algorithms for static networks. Similar to our proposal, they also consider the scenario wherein the number of available interfaces is less than the number of available channels. However, their solution is designed specifically for use in those mesh networks where all traffic is directed toward specific gateway nodes.

TOPOLOGIES RELEVANT FOR WIRELESS NETWORKING

One of the main design choices for any interconnection network is the topology, which affects directly or indirectly other design considerations such as routing, switching and flow control. Topology refers to the configuration of the network nodes and how data is transmitted through that configuration. In addition, it includes characteristics such as the degree and diameter of the network. The degree is the maximum number of neighbours connected to a node. The diameter is the maximum shortest distance between any pair of nodes. Researchers have proposed various topologies [10, 26, 2]. Various topologies are shown like Bus, Fully connected or all-to-all, a Circular Ring, a Star, a line, a Binary tree, Mesh (Torus), Hypermeshes, or even Random networks. In this section, I briefly discuss popular topologies that are relevant for wireless networking. Table (2.1) briefly provide a quick overview of that topologies relevance to wireless networks.

1. ***Bus Topology****:* The bus topology has been used extensively by LANs. Bus topology is the most common type of interconnection networks since it can be implemented easily with a cheap hardware cost. A unique characteristic of a shared medium is its ability to support broadcast, in which all nodes on the medium can monitor network activities and receive the information transmitted on the shared medium.

Although, this topology allows only one pair of nodes to communicate at any given time instance. This deadly bottleneck makes the bus topology saturate quickly for a large number of nodes.

2. ***Star Topology*****:** star topology is the most common infrastructure in wireless networking. It is a single-hop interconnect in which all nodes are within direct communication range — usually 30 to 100 meters [7] for small networks — to the central communication unit. It is well suited for Point to Multipoint communication. A typical star topology network. Star topology has also more application in cellular systems, WLAN, and satellite systems in which one satellite station communicates to multiple ground stations. Disadvantage, if the central unit fails then everything connected to it is down.

3. ***Line or Chain Topology*****:** In Chain, all communication nodes reside on a single path line topology to form a point-to-point network topology. Each network node directly communicates to only one other node. A typical topology of a point-to-point network. Wireless point-to-point systems are often used in wireless "backbone" systems such as microwave relay communications. The biggest disadvantage of a point-to-point wireless system is, that it is strictly a one-to-one connection. This means that there is no redundancy in such a network at all. If the RF link between two point-to-point radios is not robust, the communicated data can be lost. In a line network with N nodes, the diameter is (*N-1*), average distance is $N-1$ 2 , and bisection width is 1.

4. ***Ring Topology***: ring topology is also a P2P network topology. In a ring, each node is connected in the form of a closed loop of the communication medium. Signals travel in one direction from one node to all other nodes around the loop and all nodes are working as repeaters. Above Figure shows a ring topology. A ring makes a poor interconnection network due to its large diameter and poor fault tolerance since it takes more radio hops to reach distant node.

5. ***Tree Topology*****:** The tree topology is essentially a hybrid of the bus and star layouts. This topology has a root node connected to a certain number of descendant nodes. Each of these nodes is in turn connected to a disjoint set of descendants. A node with no descendant is a leaf node. Above Figure shows a tree topology. The biggest drawback of the tree topology as a general purpose interconnection network is that the root and the nodes close to it become a bottleneck. Additionally, there are no alternative paths between any pair of nodes.

6. ***Fully Connected Mesh Topology*****:** Such a mesh might seem an obvious first approach to interconnecting nodes. A mesh topology shown in Figure (2.1- *d*) provides each device with a P2P connection to every other device in the network. These are most commonly used in WAN's, which connect networks over telecommunication links. Mesh networks provide redundancy, in the event of a link failure. Meshed networks enable data to be routed through any other site connected to the network. Because each device has a P2P connection to every other device, mesh topologies are the most expensive and difficult to maintain. I will investigate this topology under the assumption that in a wireless network, each node needs one communication channel to communicate with other nodes. Using this assumption the number of switches that need to have the same topology in wired networks will be reduced to N instead of $N(N-1)$ in wired networks to switch from channel to the other. This assumption will lead to the configuration present in Figure (2.1-*i*) and I will discuss it later.

7. ***Spanning Bus Hypermesh*****:** The hypermesh network consists of communication nodes, which are constructed from routers and switches. Therefore, any node in the network can receive and forward data packets on behalf of other nodes that may not be within direct transmission range of their destination. A typical example of a 2-D hypermesh implementation is illustrated in Figure (2.1-*h*), which is the spanning bus hypercube (SBH) proposed. In addition it has been further studied by [6, 8]. The topology has very low diameter, and the average distance between nodes scales very well with network size.

8. ***Distributed Crossbar Switch Hypermesh***: Another alternative way of connecting multiple computers is to simply connect every node to every other node by means of multiple channels. Such configuration can be achieved with a topology of distributed crossbar switch hypermesh cluster proposed by [9] and subsequently expanded by Old-Khaua in [3], it is depicted in Figure (2.1-*i*). This topology gives the best possibilities for parallel programming tasks, because it does not require complicated node scheduling techniques. It has the node degree equal to one and the delay of internode messages is equal for every node pair. The number of channels for an interconnection of N nodes is equal to N, which makes it unsuitable for a large number of nodes. Since the number of channels becomes very large, the bandwidth will degrade substantially.

METRICS FOR NETWORK TOPOLOGIES

Diameter: The distance between the farthest two nodes in the network. Metric for worst-case latency.

Node Degree: Number of channels connecting that node to its neighbours.

Bisection Width: The bisection width of a network is the minimum number of channels cut when the network is divided into two equal halves.

Pin-Out: Is the number of pins per node or the number of I/Os available per router.

Cost: The number of links or switches (whichever is asymptotically higher) is an important contributor to cost. However, a number of other factors, such as the ability to layout the network, the length of channels, fanout, etc., also factor in to the cost.

Regularity: A network is regular when all nodes have the same degree.

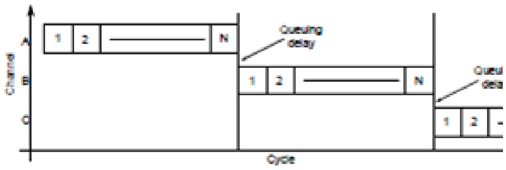
Routing: The address header of a message carries the information needed by routing hardware inside a switch to determine the right outgoing channel, which brings the data nearer to its destination. The objective of a routing algorithm is to discover efficient paths to obtain high system throughput. Many deterministic and adaptive routing algorithms have been proposed in the literature. Deterministic routing algorithms always supply the same path between a given source/destination pair. Adaptive routing schemes try to find dynamically alternative paths through the network in the case of overloaded network paths or even broken links. Nevertheless, adaptive routing has not found its way into real hardware yet [6]. Adaptive routing is out of the scope of this work. Since I know the network topology of the whole network, distributed routing algorithms are best fit to regular topologies since it does not relay on central authority. The same routing algorithm can be used in the communicating nodes. With distributed routing, the header of a packet is very compact. It only requires the destination address and a few implementation dependent control bits

SWITCHING

The term switching refers to the transfer method of how data is forwarded from the source to the destination in a network. Two main packet switching techniques, as depicted in are used in today's networks, store
& forward and cut-through switching respectively. The first technique transmits a packet completely across one channel before the transmission across the next channel started. Since the packet may be competing with other messages for access to a channel, a queuing delay may be incurred while waiting for the channel to become available. This mechanism needs an upper bound for the packet size and some buffer space to store one or several packets temporary [31, 26, 2]. This is the common switching technique found in LAN/WANs, because it is easier to implement and the recovery of transmission errors involves only the two participating network stages. Newer SANs like ServerNet, Myrinet and QsNet use cut-through switching (also referred to as wormhole switching), where the data is immediately forwarded to the next stage as soon as the address header is decoded. one sees packets transmission over their channel is pipelined, with each phit being transmitted across the next channel as soon as it arrives.
A phit is the unit of information that can be transferred across a physical channel in a single clock cycle. Cut-through switching hubs exhibit slightly shorter latency than store-and-forward switches. In addition, it requires only a small amount of buffer space which is an advantage of wormhole switching. However for wireless environment, error handling is more complicated, since more network stages are involved due to packets or flits blocking as traffic increases [3]. Corrupted data might be forwarded towards the destination before it is recognized as erroneous.

WIRELESS MAC PROTOCOLS

A crucial part of a wireless communication system is the MAC protocol. The MAC protocol is responsible for regulating the usage of the communication medium, and this is done through a channel access mechanism. A channel access mechanism is a way to divide the main resource between nodes, the radio channel, by regulating the use of it. MAC for wireless networks can be categorized into three groups.



Time space diagram showing store and forword packet switching.

Time space diagram showing cut through packet switghing.

The fixed assignment set (Channel Partitioning set) divide channel into smaller "pieces" (time slots, frequency) and have schemes like Time Division Multiple Access (TDMA), Code division multiple access (CDMA) and Frequency Division Multiple Access (FDMA). These protocols lack the flexibility in allocating resources and thus have problems with configuration changes. This makes them unsuitable for dynamic and bursty wireless packet data networks. The random assignment class (Contention based schemes) such as pure Aloha, slotted Aloha, carrier sense multiple access with collision avoidance (CSMA/CA), and non/p/1-persistent CSMA [37], etc., are very flexible instead and is what is predominantly used in wireless LAN protocols. The demand assignment (Taking turns) with schemes like Token Ring, attempt to combine the nice features of both the above and tightly coordinate shared access to avoid collisions. However, special effort is needed to implement them in the wireless case (E.g. Token Ring needs to know its neighbours).
As described a CSMA protocol works as follows. A station desiring to transmit senses the medium. If the medium is busy (i.e., some other station is transmitting), the station defers its transmission to a later time. If the medium is sensed as free, the station is allowed to transmit. These kinds of protocols are very effective when the medium is not heavily loaded, since it allows stations to transmit with minimum delay. Nevertheless, there is always a chance of stations simultaneously sensing the medium as free and transmitting at the same time, causing a collision. Subsequent variations like p-persistent and nonpersistent CSMA significantly improve the performance. In *p-persistent* CSMA, the station

senses the broadcast medium and if it is idle, then it transmit a packet. If the medium is not idle, then it waits until it becomes idle. Once the medium is idle it sends a packet with probability *p*. Without a scheme like exponential backoff for collision resolution, *p*-persistent CSMA can be unstable when offered loads are high, as many stations begin transmission simultaneously when the current transmission ends. In *non-persistent CSMA,* a station will set a random time interval when it senses that the channel is busy and tries to transmit again after that instead of continuously monitoring the channel. Packet transmission may be successful or not (collision).

An acknowledgement approach or the timeout scheme is used to detect a collision. The latter case will cause significant delay. In order to overcome the collision problem, two extensions to CSMA has been introduced, collision detection (CSMA/CD) and collision avoidance (CSMA/CA). In the former the node reads what it is transmitting, if there are differences, the node detects a collision (and thus immediately learns of transmission failure) and stops transmitting to reduce the overhead of a collision. In collision avoidance, the sender waits for an Inter Frame Spacing (IFS) before contending for the channel after the channel becomes idle.

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