Wireless Networks for Manufacturing

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Abstract

Wireless technology's like Bluetooth and W-LAN has reached a tremendous attention the last years. The manufacturing industry could probably make large benefits from using these technologies. In this paper we propose new definitions of QoS parameters to be able to handle real-time traffic in wireless networks. Initial assumptions regarding media access in a multihop network is presented. Finally simulations showing that it is possible to map the new QoS parameters on a routing algorithm.

1. Introduction

The last years, tremendous steps have been taken in the field of local wireless communication. Concepts like Bluetooth, homeRF and W-LAN have been developed. These technologies will be found in all kind of different electronic devices, like mobile phones laptops, palmtops, and watches. We have found that the industry can benefit from using these technical advances in an industrial manufacturing environment. Likely applications are; mobile test-instruments, temporarily sensors, sensors mounted at moving machine parts and autonomous robots. The traffic in these types of systems is often delay sensitive and/or error sensitive. Unfortunately are the radio media known to be stochastic in its nature, causing non-deterministic delay by re-transmissions or bit errors in the messages.

A voice channel from a bas-station to a mobile phone, this is a real-time communication link with delay constraints on the delivery of a packet, but a voice channel can tolerate a bit error rate (BER) of 0.1 %. If a sampled data value from a sensor should be sent over a communication link, such a high BER can not be tolerated. Often when real-time communication is discussed, the message delivers before deadline is the quality parameter and that is true, as long as the media not causing any message errors or any re-transmission is preformed. When the message is totally destructed by interference (forward error correction have not been able to extract the information), then the only way of recovering the information is re-transmission of the packet or accepting that the information is lost.

If we want time and safety deterministic communication over the radio media, we have to define the quality of the media. The quality of a radio channel is often defined by the bit error rate (BER). From this we can define the probability of error free delivery (P) before a deadline (D). These two parameters (P, D) can be used for setting bounds on the communication system, or stating requirements of a link or a path through a network.

The layers in a communication protocol stack are given the requirements from the layer above. And the resources from the layer below, each layer has the possibility to optimize the resources given from below with the requirements from the layer above. Each layer strives to maximize the performance of the communication system with respect to D and P.

2. Link management

Meeting quality of service (QoS) guaranties over one radio link in a real-time communication system is fundamental, but because of the insecure radio media adaptation to the physical environment is necessary. Aspects considered of a radio media is not static like bit error rate of wired link, the error rate is variable depending on the fading radio signal, multi-user interference, interference caused from certain types of equipment, like microwave ovens and arc welders. Different types of diversity can be introduced to combat the interference, examples of diversity methods are; time diversity, space diversity, code diversity or simply increase the signal power. But all these methods have their drawback; our aim is to dynamically find the most efficient method or combination of methods to maximize the performance over a link or a path over a number of links through a network. At the same time minimizing the multi-user interference (signal power) to not reduce the system performance due to the requirements of the QoS parameters P and D for the link, one method with code and time diversity is presented in [2].

3. Media access

If a large number of units should be able to communicate with each other, media access methods must be used. Deterministic media access methods like TDMA and polling schemes does not scale with increased number of units, the bandwidth must be reused on a very local basis. Today this is often done with bas-stations, dividing an operation area into cells, each unit in the cell is accessed by the base station according to a TDMA schedule or different units are given different frequencies (FDMA). This gives a static infrastructure, but when the number of units continue to increase the size of the cell will get smaller and smaller and the number of base-stations increases and the wired backbone will get more and more complex. There are already today industries that are considering putting a Bluetooth [1] units in their products in order to down load software wireless in the factory. Sooner or later there will be large amounts of such units per 100 square meters that wants to connect to access points.

One possible way out of this is the use of ad-hoc networks forming clusters depending on the density of units, the units in a cluster adapting their signal power to physical size of a cluster minimizing the multi-users interference. This is possible if each cluster is able to perform the media access function of the base-station and repeating a message through the cluster to neighbor clusters until an access point (base station) to the wired network is reached by the message. The Bluetooth [1] standard provide the possibility creating these clusters. The standard provides both synchronous messages and asynchronous messages inside a cluster, very close to the function of a field bus [15], synchronous message are time triggered and the asynchronous messages are event triggered. Also inter cluster communication is possible but there is however no support for inter cluster synchronous messages. The exchange between two clusters will be done through a gateway unit, belonging to two clusters. This unit will experience a scheduling problem to which clusters it should belong to at the moment. The standard has no support for routing a message through a network of clusters. Is it possible to match the QoS parameters P and D to each cluster and solving media access scheduling at the gateway units between two cluster, then it should be possible to route a message through a network of clusters.

Each cluster schedule the traffic inside the cluster, a synchronous channel (time-triggered) passing through the cluster is scheduled statically as virtual circuit. Event-triggered messages are scheduled dynamically as asynchronous traffic. A message must be routed either to an access point to the wired backbone or to a destination in the local area.

4. Network layer simulations

In this section an on-going work on mapping the QoS parameters D and P on a routing protocol for a wireless real-time multihop network is described. Multihop networks [3,4,5,6,7] means that a packet is able to travel longer distance then the nodes radio range (single hop), by using multiple hops over other nodes.

In this work no clustering methode is used, forcing us to use a non-deterministic media access method, combining direct sequence spread spectrum (DSSS) with carrier sense multiple access (CSMA). This is not a time deterministic media access, because of the collisions that can happen at the receiver, but as mentioned in previous chapter the cluster method will be implemented and then asynchronous messages are possible through the network. The interesting part so far is the behavior of the routing algorithms and the possibility to match the parameters P and D to an insecure media. No access points to a wired network are yet present which will probably be the bottleneck points of the local multihop network.

The advantage of a wireless multihop networks, is that it does not use an infrastructure like the base station networks. The multihop network does not have any critical nodes that the network survival is dependent upon. A transmitting node only has to reach its nearest neighbors, instead of covering the whole area; this causes less interference to the surrounding traffic. Multihop networks gives a local and distributed view of the network, and probably the most intense traffic are local in an industrial environment.

In a wireless network, a node has radio connection with multiple nodes. The environment is mobile and the radio link between nodes is subject to frequent changes, therefore the flexibility of the routing is very important.

The higher layers above the network layer is able to negotiate with the network layer protocol about the QoS parameters.

The higher layer asks the network layer protocol about the possibility to send a packet over the network with a deadline (D). The network protocol answers with a P that tells the about the possibility for a packet to reach the destination nod before D expires. Then the higher layers is able to reconsider D and try again until an agreement about the QoS parameters D and P is reached, and then the transmission starts.

Weights (W) are assigned to each radio connection (links) between neighbor nodes. The value of W reflects the QoS of a link between two nodes. In this work, the link weight W is the time between a node generating or receiving a packet until it is received correct by next destination node. Other properties can be mapped to W such as: bit error rate (BER), probability of error free delivery or number of hops.

Information is stored in every node about W for each outgoing link. The update mechanism [8] below is used to update W; this gives a moderate adaptation of W value on each link. The learning rate η moderates the update of W, to combat frequent link weight fluctuations (ping pong effects between two links)

$$Wnew = W + \eta(Wupdate - W)$$

The routing algorithm tries to find a path through the network; it calculates the sum of the weights (Wt) for different paths from source to destination. The path with the best Wt is chosen, this path gives the highest probability for a packet to reach the destination node, before deadline expires.

The routing algorithm in use at the moment is the highly dynamic Destination-Sequenced Distance-Vector routing algorithm (DSDV) [9]. DSDV is more distributed and gives less routing control overhead than the more centralized link-state method [10], which is another well-known routing algorithm.

The calculation of P given Wt and D, is one of the most critical parts of this protocol. At a source node a routing table gives Wt and the next node address along the path to the destination, D is given by the application. P is then retrieved from a look-up table with the index D and Wt. The look-up table is developed using statistics from simulations, modeling the distribution of P in respect to D and Wt.

4.1 Simulations

A discrete event, network simulator (NESU)[12] has been developed and used for the performance evaluation. NESU is a flexible platform, designed for evaluating and comparing network routing algorithms. All the nodes have their individual parameters, such as speed, trajectory, and packet intensity etc. The nodes can move in a rectangular region (in this case 60 x 60 m) according to a given motion model. All nodes have a fixed radio transmitting power, which in our case gives a transmitting radius about 20 m, depending on the interference in the area. The radio channel model [2,13] determines the radio connection between two nodes, the BER is calculated for every packet sent over the link. If the BER ratio is over a specified threshold, the packet is considered destroyed.

A 25-node mobile multihop network has been simulated, using the following simulation parameters. The radio transmitter/receiver has been assumed the PRISM chipset [14]. The PRISM chipset gives a bandwidth of 1Mbit/s and a transmitting power of 63 mw, it is based on DSSS multiplexing. The nodes move with a speed ranging from 0 to 3 m/s. The time between two data packets are generated at each node, is exponential distributed. If there is no possible path between source and destination the packet is deleted and counted as destroyed, a data packet is 3000 bits long and takes 3ms to send one hop.

In this, ongoing work initial simulations have shown following results: When the node motion is Brownian, there is a possibility that the nodes are grouped into different clusters without any connections. Due to this effect, only 85% of correct arrival are reached even if the deadline approaches infinity, this can be considered by power control inside a cluster where the nodes control their transmitting power according to the density of nodes.

We have also investigated a more likely motion model for the nodes, where the nodes are moving in a more predictable way. The intense traffic with small deadlines (20ms, average 1,5 hop) is local, typically this can be a moving smart sensor sampling a value on a large machine sending the value to a smart actuator. An autonomous robot traveling around the factory delivering things at different machines, has a less intense but more ”global” traffic with longer deadline (50ms, average 2,5 hop). Some nodes are not mobile at all they may be control computers sampling data from sensors and sending data to actuators. In a more planed environment like this, about 95% of the packets arrive correct before their deadline is expired. Multi-user interference in this case causes packet loss. Collisions occur when two nodes tries to send to the same node at the same time or when a node is busy transmitting and another nod tries to reach the busy node. These collisions are very time consuming and the deadline expires sometimes, because of re-transmission.

Ppredicted	Preal
0.3	0.34
0.4	0.39
0.5	0.50
0.6	0.62
0.7	0.73
0.8	0.82
0.9	0.89
1.0	0.97

Table 1: Real probability Vs predicted probability for a message path through the network before deadline is expired.

Although the degree of correct arrival have not been the best depending on the insecure radio media and collisions, the prediction of a packets correct arrival is possible (Table1). This is the key to map the parameters P and D to a multihop network. We can say that a message has probability P of reaching its destination before the deadline is expired.

5. Conclusions

Industries have a great interest of using the wireless technical advances in an industrial manufacturing environment. But the problem is that today, are the definitions for real-time communication traffic not suitable for the radio media.

The ability to say that a message has a probability of correct delivery to destination before deadline gives the opportunity to discuss real-time communication over the wireless media.

The multihop network simulations show that the one most important factor for delivering a packet in time is the control of collisions in receiving nodes, which possible can be done with clusters and another media access protocol then the combining of DSSS and CSMA.

Another important guarantee is that every node in the network has a path to the other nodes. This problem can be solved with clusters that adapt their physical size to the density of nodes. The fact that multihop network is scaleable with respect to bandwidth when new nodes are added is very much in favor of these network.

6. Future work

We will focus our future work on refining the protocol and dealing with the receiving collision problem, this will be done by introducing the method of clustering nodes and use a time deterministic media access scheme inside each cluster.

The scheduling protocol for the gateway nodes between two clusters must be dealt with. And the parameters P and D must be mapped on this schedule.

One other thing that should be looked into are the use of power control to control the physical cluster size with respect to the density of nodes.

7. References

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