The topology construction algorithm in Bluetooth wireless network

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Abstract

Bluetooth is a new ad hoc wireless network protocol, which is designed in a short-range radio link between portable devices. Key features are robustness, low complexity, low power, and low cost. Although the current protocol describes that devices can be connected into two basic units, piconets and scatternets, it has no specification on how the devices are connected. This proposal plans a research on the topology construction algorithm to deal with this issue. The proposed algorithm is self configuring and self healing to ensure the robustness under different channel conditions and disturbances. Further, the proposed algorithm has the property of low overlapping between different piconets and ensures low power consumption of the entire network. The importance of such algorithms is discussed and the required facilities of the proposed research are also described.

1 Introduction

Bluetooth is a new ad hoc wireless network protocol, which is designed in a short-range radio link intended to replace the cable(s) connecting portable and/or fixed electronic devices. Key features are robustness, low complexity, low power, and low cost. This proposal concerns the topology control issues in Bluetooth wireless networks, which, I believe, play an important role in the technology of ad hoc networks. Specifically, I am going to address the following questions in Bluetooth networks:

- Understand how topology construction affects the performance of Bluetooth networks.

  The topology construction protocol is used to form piconets, assign slaves and masters in a piconet, and interconnect piconets into scatternet, where piconet, scatternet, slave and master will be introduced soon in section 1.1. Not like current cellular phone system, where the topology is strictly preconfigured (hexagon topology), the current Bluetooth protocols put no constraints on the topology of the whole system. Yet the topology certainly affects its operation and performance. For example, the routing algorithms largely depend on how the devices are organized; the energy consumptions are also determined by the topology of the system; even the topology will affect the data rate and hence affect the robustness of the system.

- Design algorithms which have the property of self-configuration and self-healing.

  Ad hoc wireless network environment is a dynamic system in the sense that the channel condition is changing and devices may be mobile. Therefore new devices may join or leave the network; devices may go dead because of function failure or power exhaustion; The established links may be destroyed and new connections must be found. In these cases, self-configuration and self-healing are important in order to ensure the robustness of the system.

- Set up appropriate experimental equipment to verify the effectiveness of the algorithms in real environments.

This proposal is organized as follows. In this section, I briefly review the Bluetooth protocol and describe my motivation and objectives. In section 2, I give a summary of previous work. The proposed research is presented in section 3. The significance and impact of this research is discussed in section 4. Section 5 gives an estimation of the facilities required.

1.1 What is Bluetooth? [1] [2]

Recently, a new radio interface called Bluetooth has been developed to enable users to rapidly interconnect handheld electronic devices such as cellular phones, palm devices or notebook computers. Although current portable devices can use infrared links to communicate with each other and the infrared transceivers are inexpensive, they have a limited range(1-2m), require direct line-of sight, and are sensitive to direction. In contrast, radios have much greater range, can propagate around objects. At the end of 1997, several companies in the communications and PC industries identified the desires for local connectivity between electronics devices using radios. In February 1998, five major companies, Ericsson, Nokia, IBM, Toshiba and Intel, formed a special interest group(SIG) to fulfill this desire and developed a radio interface named Bluetooth. Other thousands of companies adopt the Bluetooth technology since then. The first version of the Bluetoooth specification incorporating both radio protocols and control software was published a year and half after the foundation of SIG. Conservative estimates foresee several hundred million Bluetooth enabled devices in the coming five years [1].

Bluetooth operates in the 2.4 GHz ISM band. It is an unlicensed band in most countries. However, microwave ovens and lighting also operate in this band whose high-powered transmitters will cause great interference to the Bluetooth devices. At the same time because the low power requirements of the Bluetooth transmitter we can't improve the power level. Therefore a frequency hopping (FH) tranceiver is used to combat fading and interference which also results from the existence of multiple uncoordinated networks. For full duplex transmission, a Time-Division Duplex (TDD) scheme is used. On the channel, information is exchanged through packets. The Bluetooth system provides a point-to-point connection (only two Bluetooth devices involved), or a point-to-multipoint connection. Two or more devices sharing the same channel form a *piconet*. One Bluetooth device acts as the master of the piconet, whereas the other device(s) acts as slave(s). Up to seven slaves can be active in the piconet. And many more slaves can remain locked to the master in a so-called parked state. These parked slaves cannot be active on the channel, but remain synchronized to the master. For all of the active and parked slaves, the channel access is controlled by the master.

Multiple piconets with overlapping coverage areas form a *scatternet*. Each piconet hops independently with the hopping sequence and phase as determined by its master. In each piconet, there is only one master. One device can be in different piconets in the same scatternet and it can act

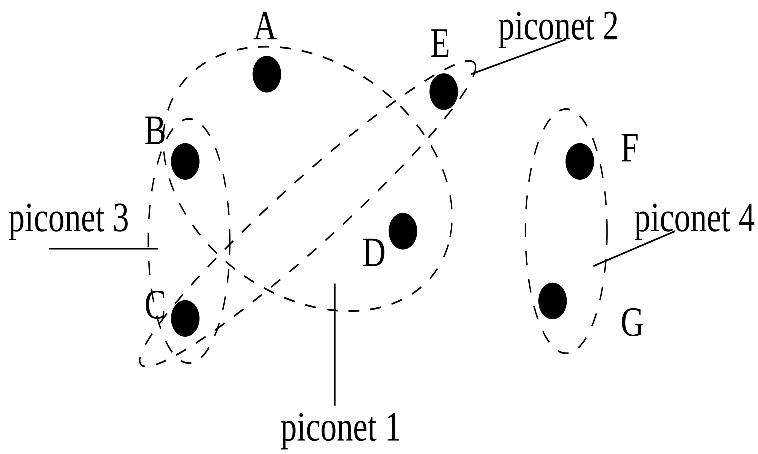

Figure 1: Typical topology of Bluetooth scatternets.

as master or slave in each piconet but can not be master in each of them. The channel access is independent in each piconet. The role of master and slave can be switched when one of the slave wants to be the master. When a device participates in different piconets, there is a limitation of time slots utilization because one device can't transmit data in the same slot in two piconets. The device can transfer data in one piconet in the time slots that are not used by another piconet. Not all the packet types can be transmitted arbitrarily in two piconets. Although the device that creates the piconet is the master, it can switch to slave if one of the slave in the piconet wants to become a master.

When two piconets hop at the same frequency, a collision occurs. When more and more piconets exist in the same area, the probability of collision will increase. As a result the performance will decrease when two piconets hop at the same frequency. The protocol of the traffic coordination, routing in a scatternet and the scatternet formation is not specified in the specification of Bluetooth. It is still a subject for future study.

1.2 Motivation and objectives

My proposal is motivated by the possible problems arising from the configuration of a typical scatternet as shown in figure 1:

- This configuration has no consideration of the local position of each device. The covered geographical area of different piconets overlap with each other. The resulting topology of piconets is very complex. The routing algorithm may need to run a long time merely in order

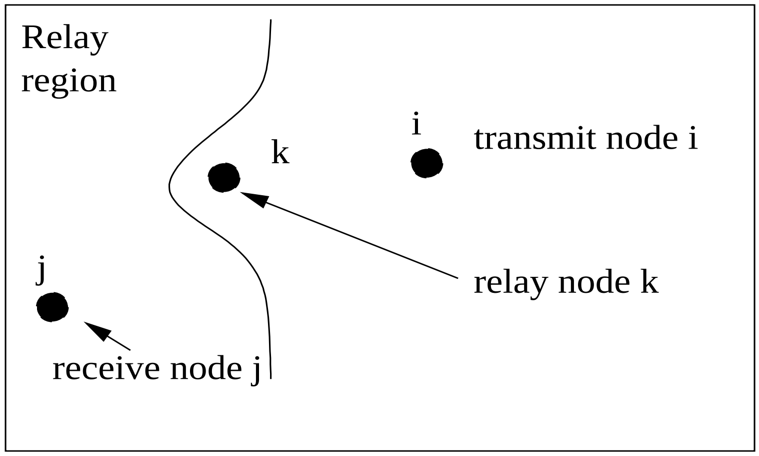

Figure 2: Relay region.

to send a packet to its neighboring device.

- Because there are many piconets existing in the same area, the possibility of packet collision between different piconets becomes larger. This is because Bluetooth adopts FH multiple access scheme and it is possible two users transmit at the same frequency at the same time slot. If the service areas of different piconets do not overlap or only overlap a little, frequency reuse can be realized. This is also called space division multiple access (SDMA).

- A network with such a topology consumes a lot of power. In a wireless system, the transmit power falls as $1/d^n$, $n \geq 2$, where d is the distance between the transmitter and the receiver. This fact means sometimes transmitting between two distant devices directly consumes much more power than relaying the information by an intermediate device. This is shown in figure 2 [5] [6]. If a device j is in the relay region, the transmit device i is better to connect to j through a relay device k in order to save energy. In figure 1, the transmission C$\rightarrow$E can be implemented by C$\rightarrow$D$\rightarrow$E in order to save energy.

- There is no guarantee of strong connectivity. Strong connectivity means there exists at least on path between any two nodes in the system. For example, in figure 1, there is no path between nodes in piconet 1 and those in piconet 4.

The above problems occur because there is no constraint on topology construction in Bluetooth specification. The piconets or scatternets are created on the fly regardless of power consuming, complexity and frequency reuse. So the main objective of this proposal is to put forward a distributed topology construction algorithm which has the following properties:

- reduced complexity
- less energy consumption
- strong connectivity
- self-configuration and self-healing

2 Summary of previous work

The topology construction algorithms have been studied in some literatures. In [3], a clustering algorithm has been proposed to partition mobile users into clusters to support routing and network management. A cluster is defined as a subset of vertices, whose induced graph is connected. The overheads and the convergence time are investigated. Further this algorithm doesn't require a preconfigured topology assumption which is often given in other clustering algorithms. But this algorithm doesn't consider the power consumption issue and it requires the GPS information of every node. Here and in the sequel, a node means a device in the network.

Similarly in [9], a hierarchical clustering algorithm is designed, but the geographic radius of the cluster cannot be guaranteed. This certainly poses the power consumption issue. In [10], the clustering algorithm is called LEACH, which cannot guarantee the placement and the number of clusters in a system. The convergence of these two algorithms under perturbations are not optimized.

In [8], the authors present a GS^3 algorithm which is distributed, scalable, self-configuration and self-healing. This algorithm enables nodes to self-organize the system into a hexagon topology. But the open issue of this algorithm is how to select the value of R, which is the maximum distance of the geometric center of a cell and any point in it. Without the knowledge of the whole system, it is difficult to get an optimal value for R. If R is too big, the number of the nodes in a cell is too large to be accommodated into a piconet. Further, the power consumption is too much when R is big. If R is too small, it is impossible to realize the hexagon topology when the level of distribution density of nodes is not even. In this case, there may exist a band with no node to establish a cell. This disadvantage comes from the preconfigured hexagon topology which cannot adapt to the real distribution density of the nodes.

The algorithm in [7] is also a topology construction algorithm using distributed logic. However, in order to satisfy the strong connectivity condition, this algorithm adopts a centralized way to control the network formation, and thus is not scalable.

In [5] and [6], the energy consumption issue is dealt with. The goal in these papers is to self-organize a minimum energy consumption network. As the work of [3], the GPS information is required. The extension of this algorithm to Bluetooth needs to be investigated since there is no piconet or scatternet conceptions in this algorithm.

3 Proposed research

By carefully examining the specification of Bluetooth protocol, I propose to solve the topology construction problem. In last section, the topology construction algorithms in the literature are reviewed. Each of them has advantages and disadvantages. In my proposed research, I am going to design an algorithm which is suitable for Bluetooth protocol, which put some constraints on the algorithm design. For example,

- Since each piconet has less than 7 devices, the geometric radius of a piconet needs to vary according to the level of distributed density of nodes. The preconfigured hexagon topology cannot be used.

- In order to reuse precious frequency, geometric overlap between different piconets needs to keep small.

The proposed algorithm research should consider the issues listed in the following subsections. Although it may be impossible to find an algorithm satisfying all the requirements optimally, I strive to find an algorithm which can address these issues to a satisfying level.

3.1 Reduced complexity

Reduced complexity is achieved by only allowing small overlap between neighboring piconets. The convergence time of routing algorithm is greatly affected by the complexity of network topology. Moreover, the total energy consumed in the process of routing is also determined by how many hops have been implemented. Simple topology helps the routing algorithm find the minimum hops between two nodes.

3.2 Less energy consumption

Since portable devices normally have much less power supply than stationary devices, my goal is to find a topology that reduces the power consumption of the entire network. As shown in figure 2, transmitting power is determined by the distance between the two nodes in communication. Relay and routing are necessary if the communication is between two distant nodes. The master devices have the same role as the cluster heads in [9] [3], while in [5] [6], no cluster heads are assumed in the networks. The research direction is to combine the theory of minimum power consuming in [5] [6] and clustering construction algorithms in [9] [3].

In a piconet, the master devices consume much more power than the slave devices. If the devices in a network have the same level of power supply, it is not fair to let a fixed device in a piconet act as a master devices. One way to solve this is to let each device in the piconet alternates as master or slave. This may pose a lot of serious problems in the piconet related to routing, channel changing and inter-piconet communications. This is an interesting research issue which can ensure the longevity of the network.

3.3 Strong connectivity

Strong connectivity is important to ensure any two nodes in the network can communicate. This is a basic requirement for the proposed algorithm.

3.4 Self configuration and self healing

In the specification of Bluetooth, using *Inquiry Procedure* and *Paging procedure*, devices can self configure into piconets or scatternets. However, the Bluetooth network is a (mobile) wireless network. Disturbance affects the operation of the network. Hence the topology construction algorithm must have the property of self-healing. The disturbance comes in several ways:

- Because the devices are mobile, they can go into the system or leave the system arbitrarily. When a device finishes the communication, it can go into the sleep mode. After a certain amount of time, it wakes up to be active again. When a device exhausts its battery power, this device goes dead. This means the amount of devices in the system varies frequently.

- When a device moves from one point to another point, the communication channels between itself and any other devices in the piconet change, e.g., a line of sight (LOS) channel may be blocked by the furniture. Good channels may turn into poor channels. Previous supported high data rate is no longer supported after the movement. In order to continue the communication, new piconets may be formed. Thus the topology has been changed.

In both of the above scenarios, the proposed algorithm should keep the network functioning properly. We propose to construct the topology according to the local knowledge. Thus the effect of disturbance is confined in a small area, not affecting the stability of the whole network.

4 Significance and Impact

Bluetooth is a preliminary protocol intended to provide local wireless connectivity between portable devices. There are many issues open for future study, such as scatternet formation, traffic control and routing. Topology construction protocol deals with scatternet formation and routing in Bluetooth. A distributed, low power consuming, self configuring and self healing topology construction algorithm is very important to pave the way to the large scale application of Bluetooth devices.

5 Facilities needed

Different facilities will be needed in different phase of research. In the phase of algorithm development, a Unix workstation or a PC is enough to simulate the algorithm. Since the baseband specification is not important to the topology construction algorithm, no digital simulation equipment is needed.

In order to verify the correctness of the algorithm in real life, a number of Bluetooth devices are necessary. Some of these devices have to be mobile. Different channel conditions are required to check the self-healing property, such as typical urban (TU) enviroment, rural area (RA) enviroment and hill terrain (HT) enviroment. A vehicle that can carry the devices to different environments is required to implement the experiment.

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