EXTENDING MONITORING TIME OF BLUETOOTH PATIENT ADHOC NETWORKS

J.G. Castano*, D.E. Alfaro* and M.Ekström*, **

*Mälardalen University, Department of Computer Science and Electronics, Västerås, Sweden
**School of Computer science and Information Systems, Edith Cowan University, Australia

javier.garcia.castano@mdh.se

Abstract: The expenses for the public health service are developing rapidly, the challenge is to raise or at least maintain the present level of health care provision without ending up in an uncontrolled cost explosion. A new generation of wireless technology applications for the medical field to improve the quality and to reduce the cost of patient care are being deployed. Particularly wireless patient monitoring, also known as wireless telemetry in hospitals or in home care is becoming very popular.

The most crucial features of wearable health monitoring equipment are long battery life, lightweight, and small dimensions. Clearly the advent of new battery technologies such as lithium Ion, have dramatically increased energy capacity of a battery and as a result made many wireless applications feasible. However, consideration must still be given to design wireless systems such that the optimum power consumption is achieved.

This work is focusing on the design and development of wearable wireless biomedical sensor ad-hoc networks optimising the battery life of the network.

Simulation results are provided for static and dynamic scatternet configurations showing an increment of the total scatternet life for high-density networks.

Introduction

After developing several wireless biomedical sensors [1,2] at our department the next research step is connecting them to a network. The regular network access way is achieved by connecting patients to access points. Access points will then work as bridges for different communications technologies e.g. Ethernet, WLAN or GPRS.

However this topology is not well suited for all scenarios like e.g. catastrophes or simply the fact that there are far more sensors than access points. Usually these scenarios are present outdoors where neither network infrastructure nor access points are available.

In this case the sensors should form an ad-hoc network providing full cover of the patient area. When this problem is solved with Bluetooth, topology design must be carefully considered since the power consumption is highly dependent on the transmitted output power. It will be very inappropriate to connect a slave sensor to a far master thus increasing the power consumption of both sensors and dramatically reducing their battery lifes.

The pre-study of the system shows that out of 8 patients one must become a master and the rest will be slaves, thus forming a piconet with the maximum number of active slaves [3]. If power consumption is associated to radio usage then Figure 1 depicts the distribution of power consumption. Tx and Rx stand for transmission and reception respectively.

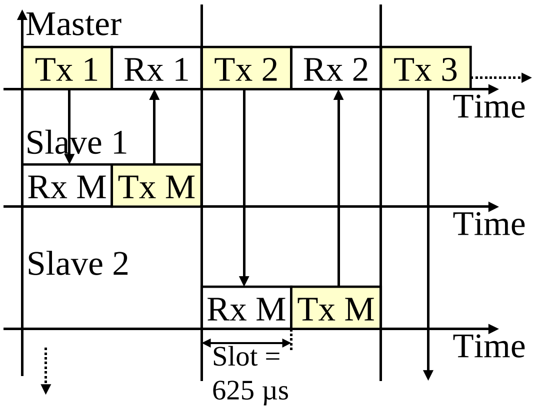

Figure 1: Usage of radio & distribution of the transmitted power.

Many studies have been performed in order to find out which is the optimal scatternet formation algorithm. Some algorithms focus on the distribution of the data rate and the quality of service [4] and there are works with real time approaches [5]. However in this study the scatternet formation algorithm is optimised to distribute power consumption, thus extending the life of the scatternet.

The problem with power consumption has been addressed in many studies in order to maximize battery life [6,7]. In this paper no low power states are used and thereby achieved results give the worst-case results.

One of the limitations imposed by Bluetooth technology is that the basic network topology is a star with one master that centralizes all traffic with up to seven active slaves. Slaves can only communicate with the master; which sets the synchronization as well as the channel to communicate.

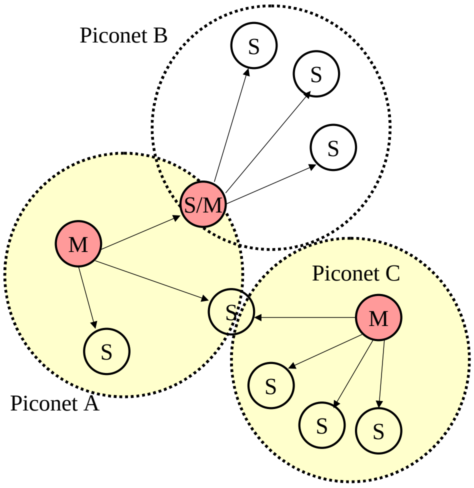

Figure 2: Scatternet with 3 Piconets.

If a piconet is considered (see Figure 2) the master of the piconet has a higher power consumption than the slaves, because the master activates its radio every second slot while the slaves activates its radio for transmitting every 2*(number of slaves) slots (see Figure 1).

Figure 1 shows a piconet where the master always has something to transmit to each single slave, however this behaviour is not realistic since the master patient will only transmit its own data together with the collected data from its slaves to a bridge. Instead the master transmits a NULL or POLL packet to its slaves. The NULL packet is 126 bits long and consists of the channel access code and packet header [8].

If there are more than 8 patients in the area a scatternet should be formed. A scatternet is a group of piconets, where the piconets are connected using a bridge device (a device that belongs to two piconets). The bridge device can be a device working as master in one piconet and as slave in the other, or a device working as slave in both piconets as shown in Figure 2.

The scatternet must be connected to one or several end-points for monitoring purpose meaning that traffic must be routed by bridge nodes. Bridge nodes will then activate their radio longer and at a higher frequency than other nodes, which increases their power consumption. The higher consumption of masters and bridges causes that these devices finish their batteries faster, i.e. their battery lifes are shorter. If we consider that the life of the network (piconet or scatternet) is the time from when the network is formed until one device runs out of its battery, the life of the network will be then reduced to the time when the first master or bridge exhausts its battery.

So, in an ordinary Bluetooth behaviour, considering multislave transmission, the network will usually go down because of a master or a bridge. This is a big problem, because once a master is dead, its piconet is dead as there is no way to communicate between two slaves without a master.

And also, the problem can be more serious, if the dead node was working as a bridge between two other piconets there will be no way to communicate the information of the devices of those two piconets.

When analyzing the battery left in the devices when the network is down, another problem is found: the devices that have been working as masters or bridges have almost run out of battery, while devices which were configured as slaves keep almost all their battery left.

A new concept is now introduced, the total battery of the network, understanding it as the sum of all battery levels. The previous paragraphs reveal that when a scatternet is dead, the total battery level of the network is still high due to the batteries left in the slaves.

The content of this paper is organized as follows: The materials and methods section explains the set up for the simulations and the description of both the static and the dynamic algorithms. The results section gives an accurate description of the algorithms behaviour and explains the improvements of the different implementations. Finally in the discussion and conclusions sections an analysis of the results together with application areas and limitations of this work are presented.

Materials and Methods

First the set up of the simulation scenario must be understood to be able to get a good understanding of the development of the simulator as well as the results. The starting point is a group of patients, each one equipped with a Bluetooth transceiver. From now on it is considered that every single patient continuously transmits data with the same data rate. The data rate is low enough to not collapse the network. There are no priorities in the system, thus every sensor will be assigned a time slot in a balanced round robin basis as Bluetooth specification details [4]. Another prerequisite is that all nodes are connected to the scatternet but this does not mean that all nodes see all nodes.

The simulator has been developed with Labwindows CVI. This simulator accepts the coordinates for the location of patients as inputs and it generates a scatternet topology in a random fashion, an optimised static solution and a dynamic topology with graphs of the battery evolution for each single device and a comparison of the battery life for 3 given topologies.

The next paragraphs describe the algorithms used in the simulator starting with an explanation of how to choose the best master for each single piconet, followed by the static scatternet and finally the dynamic scatternet algorithm.

Election of the master patient for1 piconet:

The master patient must be the one that minimizes the distances to all slaves, thereby minimizing the transmission power. (1) describes the algorithm to find the optimal master patient where M is the master and $RSSI_i$ is the Received Signal Strength Indicator for each single slave.

$$M = Max(\sum RSSI_i) \tag{1}$$

RSSI is a value that can be measured by every Bluetooth enabled device by issuing the HCI_Read_RSSI command. To be able to get the RSSI value a previous Bluetooth connection must be established. This is done at set up time for each single device. First every node will issue an Inquiry to find out the Bluetooth Device Addresses BDAs of surrounding nodes. After that it will create an Asynchronous Connection Link ACL connection and finally it will execute the HCI_Read_RSSI command. If the Friis equation is used an estimation of the RSSI is then obtained [9].

Static Patient Scatternet Formation Algorithm:

An algorithm has been developed in order to establish the less power consuming topology. Now the problem is not to find the right master for a single piconet but to find the right masters that ensure that all patients are connected. In order to get this topology all possible configurations are analyzed implying that every single node is tested as a master.

Formula (2) is a simplified form that describes the algorithm to configure a scatternet of N piconets, where $RSSI_B$ is the RSSI of a bridge node. Since traffic will be routed through bridges it is important to choose a closer patient to work as a bridge.

$$\begin{aligned}&Scatternet\_configuration =\\&Max[(\sum RSSI_i)_1 + .. + (\sum RSSI_i)_N]\ \& \qquad (2)\\&Max[(RSSI_B)_1 + .. + (RSSI_B)_N]\end{aligned}$$

The algorithm iterates trying no minimize N, thus minimizing the number of masters and bridges as these are the limiting devices for the life of the scatternet as discussed above.

The algorithm ensures that all devices are seen at least by one master.

Bridges are selected so they can connect a couple of piconets minimizing the power consumption and ensuring that there is at least one way to connect the N piconets but this does not mean that each couple of piconets are connected to each other. Bridges may be masters (a master in one piconet may work as a slave in another) or slaves (they are slaves in two different piconets).

Common slaves are assigned as follows:

Devices that are only seen by one master are directly connected to that master.

For devices seen by more than one master the following algorithm is used: First a list is created with devices and the calculated difference of highest and second highest RSSI received from the different masters, Difference Value. This list is then ordered by descending value. Only values over a threshold value are considered as a low value means that the node is seen with almost the same power by two masters and is thereby not a critical device. Each of the devices in the list is then assigned the master with the highest RSSI value unless that master already is assigned 7 slaves, in that case the Difference Value is recalculated and the device list is updated. This process is repeated until all devices are connected to a piconet.

However this generates a static scatternet meaning that once the role of each device is selected it cannot be changed and as results show, the static configuration is not optimal since masters and bridges are still limiting the life of the scatternet. Therefore a dynamic reconfiguration of the scatternet that distributes the master role among other patients is required.

Dynamic Reconfiguration of the Patient Scatternet

The dynamic algorithm for scatternet is born whilst trying to make better use of the batteries of the devices to prolong the life of the scatternet. With the static algorithm, the masters were the devices that spent their battery the fastest, while most of the slaves still had most of their battery remaining. A dynamic solution that uses the battery of almost all the devices will prolong the life of the configuration. Instead of using just one configuration, the dynamic algorithm will use several scatternet configurations over time, in order to make a better use of the battery of all the devices and thereby prolong the life of the scatternet. The end of one configuration can be determined by two criterias:

a) The battery of a master reaches a threshold level. In this case a new reconfiguration as described in static patient scattenet section is created where devices with little battery will not be used as masters.
b) One device runs out of battery. In this case, the end of the configuration coincides with the end of the scatternet.

Every time a new configuration is created with the static algorithm two points need to be considered:

a) In order for a device to become a master it needs a battery level of 55 – 80 % of the medium level of all devices.
b) A simple configuration will work until the battery left in one of the masters is lower than a threshold value. The algorithm will automatically calculate this value, and the best value to get the longest life of the scatternet fluctuates between 25 and 35% of the medium battery value of all the devices.

Results

The simulation is run until one device runs out of battery. This occurs when one master or a bridge has consumed all its battery. After the simulation different results are obtained:

- Life of the scatternet (see Figure 3).
- Evolution of the consumption of the devices along time (see Figure 4).
- Graphical topology of the scatternet.

The simulations results show that when running a common random patient scatternet configuration, the life of the scatternet is shorter (see Figure 3). At the finishing time the battery of the slaves is almost full while the battery in the masters is almost extinguished.

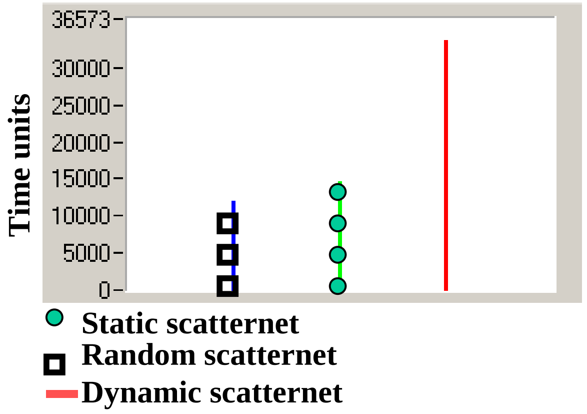

Figure 3: Life of the scatternet for static, random and dynamic algorithms.

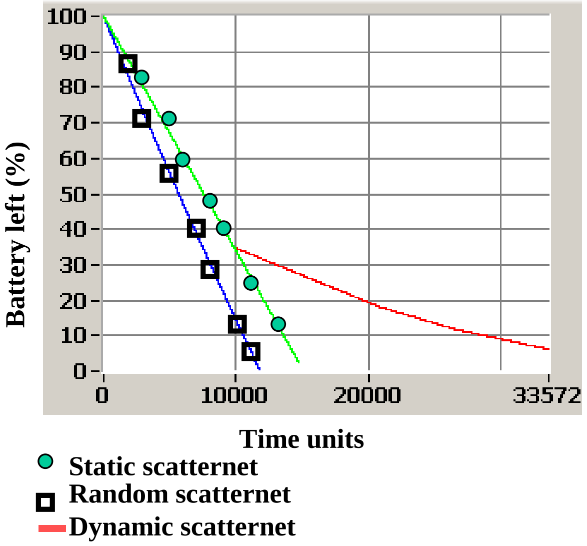

Figure 4: Battery life evolution of a device for static, random and dynamic algorithms.

The battery life of the system is increased between 15% and 30% when applying the static patient scatternet formation algorithm described above. With this improvement the battery life of the masters is longer.

The final optimization with dynamic reconfiguration gives the maximum battery life with an increase of between 200% and 300% (see Figure 3). When the scatternet dies the battery of all patients is very low. Some important goals that are achieved are:

a) The battery of almost all of the devices has been spent when the scatternet dies.
b) The life of each configuration is long enough to compensate the battery consumption that is used in every reconfiguration due to scanning procedures, which are intense in radio usage.

Discussion

Simulations have been conducted due to the lack of material devices required. The present work is based on Bluetooth specification 1.2.

However the simulator has been tuned in order to reproduce the behaviour of a Bluecore2 Bluetooth module from Cambridge Silicon Radio in an empirical way. The power consumption of the reference sensor system is composed by the consumption of a Bluetooth module together with an external microcontroller, the signal conditioning stage and a temperature sensor [10] giving an average power consumption of 180 mW / h.

Conclusions

It has been showed that for non-mobile, uniform high-density networks with low data rates the use of reconfiguration algorithms increase the battery life of the scatternet a factor of up to 300 %. This result may be of importance when deploying outdoor or no wired networks.

Test showed that the algorithms start to be effective when the number of patients is superior to 15.

Some limitations are imposed in the developed model:

- The model does not support scatternet scheduling, which means that resynchronization has not been taken into account.
- Bottlenecks and problems with data rate have been ignored.
- The effects of the dynamic configuration are ignored as well. A Bluetooth ACL link establishment could take up to 10 seconds for a couple of devices.
- The present algorithm will not support real time continuous monitoring of patients.
- The algorithms do not support mobile patients, the network must be static.
- Interferences and noise problems have also been avoided assuming a clean environment where no retransmissions are needed.
- No power saving states as Parked have been taken into account.

There is an important question that must be mentioned, is it Bluetooth the ideal solution for this type of scenarios? Bluetooth technology is intended to set up point-to-point links with support of both data and voice. Scatternet implementation is open in the specification

The answer might be found having a look to new technologies like Zigbee. This new technology reduces dramatically power consumption by means of a simpler protocol, which makes it easier to deploy a network together with a significant increment of the battery life. Still the algorithms discussed in this paper may be used generically regardless of radio technology.

References

[1] ANDREASSON, J.; Ekstrom, M., (2002); Fard, A.; Castano, J.G.; Johnson, T.; 'Remote system for patient monitoring using Bluetooth'; Sensors, 2002. Proc. of IEEE , Volume: 1 , Page(s): 304 - 307, 2002.

[2] LONNBLAD, J.; CASTANO, J.G.; EKSTROM, M.; LINDEN, M.; BACKLUND, Y., , (2004): ' Optimization of wireless Bluetooth sensor systems'; Proc. 26th Annual International EMBC 2004 Volume 1, Page(s):2133 - 2136 Vol.3, 2004.

[3] BLUETOOTH SIG Core specification, www.bluetooth.org

[4] WENSHENG ZHANG; GUOHONG CAO; , (2002): 'A flexible scatternet-wide scheduling algorithm for Bluetooth networks'; Performance, Computing, and Communications Conference, 2002. 21st IEEE International 3-5 April 2002 Page(s):291 - 298

[5] SHUN-CHUAN CHEN; HSUAN-WEI CHEN; ANG LEE; KUO-HAO CHAO; YU-CHENG HUANG; FEIPEI LAI; , (2003): 'E-Vanguard for Emergency - a wireless system for rescue and healthcare'; Enterprise Networking and Computing in Healthcare Industry, 2003. Healthcom 2003. Proceedings. 5th International Workshop on 6-7 June 2003 Page(s):29 – 35

[6] KARJALAINEN, O.; RANTALA, S.; KIVIKOSKI, M.; , (2003): 'A comparison of bluetooth low power modes'; Telecommunications, 2003. ConTEL 2003. Proceedings of the 7th International Conference on Volume 1, 2003 Page(s):121 - 128

[7] YANG-ICK JOO; TAE-JIN LEE; DOO SEOP EOM; YEONWOO LEE; KYUN HYON TCHAH; , (2003) :'Power-efficient and QoS-aware scheduling in Bluetooth scatternet for wireless PANs'; Consumer Electronics, IEEE Transactions on Volume 49, Issue 4, Nov. 2003 Page(s): 1067 – 1072

[8] ZHANG PEI; LI WEIDONG; WANG JING; WANG YOUZHEN; , (2000): 'Bluetooth-the fastest developing wireless technology'; Communication Technology Proceedings, 2000. WCC - ICCT 2000. International Conference on Volume 2, 21-25 Aug. 2000 Page(s): 1657 - 1664 vol.2

[9] CASTANO, J.G.; SVENSSON, M.; EKSTROM, M.; , (2004): 'Local positioning for wireless sensors based on Bluetooth'; Radio and Wireless Conference, 2004 IEEE 19-22 Sept. 2004 Page(s): 195 - 198

[10] CASTANO, J.G.; LONNBLAD, J.; SVENSSON, M.; CASTANO, A.G.; EKSTROM, M.; BACKLUND, Y.; , (2004) 'Steps towards a minimal mobile wireless Bluetooth sensor'; Sensors for Industry Conference, 2004. Proceedings the ISA/IEEE 2004 Page(s): 79 - 84

ISSN: 1727-1983 © 2005 IFMBE