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Roch H. Glitho (Eds.)

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5th International Workshop, MATA 2003
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Preface

The aim of the MATA workshops series is to provide a unique opportunity for researchers from the IT, Internet, and telecommunications domain, as well as related software and application developers and service providers to discuss the advances in agent technologies and their applications in next generation mobile Internet and telecommunications.

Since 1999 in Canada, MATA workshops have contributed to the creation of a research community around mobile agents and their use in telecommunication applications.

The 2003 workshop focused on recent developments in agent technologies and particularly the use of agent technologies within the fields of network management, dynamic service provisioning and management, nomadic and mobile computing, context aware services and environments, active and programmable networks, policybased services and management, ad hoc networking, peer-to-peer computing, ambient intelligence, Wireless Java, software defined radio, adaptive mobile end systems, virtual home environments, smart home, smart cars and navigation, e-learning, m-commerce, and other related 3Gb areas.

October 2003 Eric HORLAIT

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Efficient Formation of Dynamic Bluetooth Scatternet via Mobile Agent Processing

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Abstract. During recent years, there has been an increasing interest in the research and development of Wireless Personal Area Networks (WPANs). In particular, Bluetooth has been widely acknowledged as a suitable solution to enable small electronic devices with wireless connectivity. However, a number of issues remain to be solved before Bluetooth-equipped devices can provide users with full ad-hoc networking capabilities. This paper explores and discusses the applicability of mobile agent technology to address a specific issue in Bluetooth networks: the scatternet formation problem. It is argued that mobile agent technology can be efficiently employed to solve this particular problem in Bluetooth WPANs, overcoming restrictions seen in existing schemes. Simulations results demonstrate the effectiveness of using mobile processing to solve the scatternet formation problem.

Keywords: Mobile agents, mobile processing, Bluetooth, scatternet formation, ad-hoc networks, and wireless personal area networks.

1 Introduction

Providing small computing devices with wireless connectivity is one of the key steps toward enabling mobile users with ubiquitous computing capability. To this effect, Bluetooth technology has been widely adopted as an alternative solution to other wireless technologies. Its simplified radio circuitry is specifically tailored to meet the requirements of small electronic gadgets, such as cellular phones and personal digital assistants. Its current specification provides wireless connectivity of up to 10 metres, and a maximum data rate of 721 Kbps [1]. Wider coverage areas are also possible, e.g. up to 100 metres, while additional specifications are being developed to reach data rates as high as 55 Mbps [2]. Given these features, and a target price of a few dollars, Bluetooth is widely considered a promising technology to enable WPANs [3], [4]. However, before this possibility becomes a reality, a number of issues inherent to the Bluetooth wireless architecture must be addressed. One particular problem is the need for efficient solutions to configure ***scatternets***, a term coined to Bluetooth-enabled ad-hoc networks. ***Scatternets*** possess unique characteristics that are inherent

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to the Bluetooth technology, which adds extra complexity to scatternet formation protocols. This paper presents a novel solution, in which mobile (agent) processing is employed to dynamically configure scatternets. To our knowledge, there has been no existing work reported in the literature, that applies agents technology and mobile processing to the problem of dynamic Bluetooth scatternet formation. Not including this introduction section, this paper is organized into 6 sections as follows. Section 2 reviews the basics of Bluetooth technology to give a foundation for the rest of the paper. Section 3 gives a brief description of the mobile-processing paradigm and its applicability to ad-hoc networking. Section 4 elaborates on the proposed method to solve the scatternet formation problem using mobile processing. Simulation results are presented in Section 5 to demonstrate the effectiveness of the proposed method. Finally, in Section 6 we offers concluding remarks and suggestions for future work.

2 Introduction to Bluetooth WPANs

In comparison to the wireless LAN technology, establishing a communication link between two Bluetooth enabled devices is a somewhat more intricate process. This can be primarily attributed to the mechanism used in the Bluetooth architecture for devices to gain access to the wireless channel. Such mechanism is known as Frequency-Hopping Spread Spectrum (FH-SS), which is widely acknowledged to provide high bandwidth utilization and improved noise immunity. Bluetooth devices (BDs) establish a communications link by synchronizing the pseudo-random sequence with which they sequentially access different channels in the available bandwidth according to the FH-SS mechanism [1]. To accomplish this, BDs must first become aware of their mutual existence. This is the primary objective during the first stage of the discovery procedure, known as the *inquiry* process. Once two BDs have become aware of their mutual existence, both devices are able to complete the synchronization procedure by entering the *page* state. This second stage enables one device to transfer hardware-specific data to the other, leading to the desired synchronization that precedes the *connected* state. A drawback to this scheme is that the delay incurred during the inquiry process can be as long as 10 seconds [1].

According to the current architecture of the Bluetooth technology, after a wireless link has been created between two BDs, one of the devices assumes the role of a *master*, while the other assumes the role of a *slave*. More than two BDs can connect to create a ***piconet***. In a ***piconet***, there can be only one master, and up to seven active slaves. Dual master-slave roles in a BD are also possible, but are rather avoided due to further role-swapping delays. A master BD has the task of controlling the data flow among the members of its piconet that inherently has a star topology centred at the master BD. A piconet can accommodate additional slaves as long as they assume a *parking* (inactive) role. A scheduling scheme can then be enforced to control the way in which slaves swap between *connected* or *parking* states to enable data transfer as required. In addition, a slave BD may belong to more than one piconet by assuming an active role in one of them and a parking role on the others in a rotating fashion. Such a BD, referred as a bridge, can then be used to relay data among piconets, resulting in the scatternet concept shown in Figure 1.

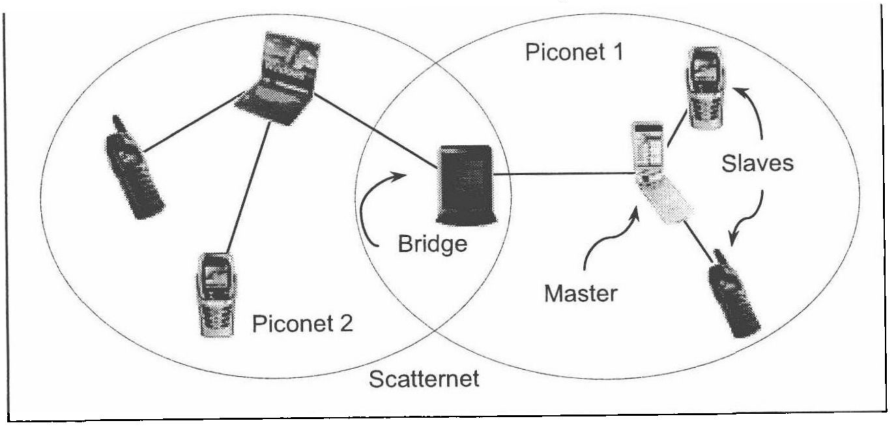


Fig. 1. A sample scatternet

Given the renewed interest by the telecommunications industry [4], an increasing number of researchers in the area have put forward proposals and investigation reports that deal with the scatternet formation problem. The scatternet formation problem can be informally stated as follows. Given a set of BDs, how can they be interconnected to best form a set of piconets that constitute an optimal scatternet? Additionally, how can a new BD be optimally connected to an existing scatternet? An optimal scatternet topology can be defined as the one that has the minimal number of piconets (or *masters,* i.e. the fewest average number of hops required between any pair of BDs. Rather than describing these existing approaches, it is important to note the assumptions behind these protocols that explain their limitations. For instance,

- BDs participating in a scatternet formation process are somehow able to initialize the protocol at roughly the same time [5], [6];
- all BDs must be within radio range of each other for the protocol to work [7], [8];
- additional BDs cannot join the scatternet at a later time [9].

It is not difficult to notice that these assumptions may not necessarily hold in practice when the Bluetooth technology is applied to support WPANs. It is therefore imperative that scatternet formation protocols be able to overcome these limitations, and adhere to the needs of the users. The next section presents some necessary background on the mobile agent paradigm as an alternative approach to the scatter network formation problem, that overcomes the limitations.

3 Applicability of Mobile Agents in Bluetooth WPANs

The applicability of the mobile agent paradigm to solve diverse networking problems has been broadly studied. Due to the dynamic nature of ad-hoc networks, the potential usefulness of mobile agent systems in this area seems natural. In fact, the incursion of mobile agent schemes into the wireless networks realm has already taken place with successful results, particularly in the routing area [10], [11]. To the best of the authors' knowledge, this is the first time that a mobile agent system is employed to address the scatternet formation problem.

Within the software context, mobile agents may be defined as self-contained units of code that can be moved across computer networks to perform a specific task on behalf of the entity that uses it. Such entity may be either a human user or a computing system. According to existing concepts, mobile agents should possess certain characteristics, such as compactness, autonomy and persistence [12]. The use of mobile agents is generally targeted at the application layer for brokering-like tasks. However, a number of systems have used this technology to address other network-level issues. In the later case, the use of mobile agent 'colonies' is a common method, where such a system is comprised of not one, but potentially many agents collaborating to achieve a given task. This same framework is employed in the novel solution we introduce in this paper.

Several mobile agent systems have been investigated and developed by the research community worldwide. Most of the existing systems make use of the Java language to implement mobile agents. The *Wave* system has alternatively been used in this and other investigations [13], [14]. Although regarded as a mobile agent system, Wave can also be viewed as a mobile processing software tool that encompasses a number of characteristics not seen in other systems [15]. In particular, Wave incorporates the notion of both a track layer and a knowledge-network layer. These mechanisms enable a robust processing architecture that supports strong migration, among other features. As a consequence, a number of intricacies that are usually the responsibility of the programmer can be instead managed by the Wave Interpreter (WI), leading to a more compact code and improved functionality [16]. These latter aspects of the Wave mobile processing system are of prime importance when considering alternative approaches in an attempt to reduce the amount of network management traffic normally seen in highly dynamic ad-hoc networks [17]. Obviously, network management traffic is an overhead that should be minimized as much as possible in such bandwidth-limited environments.

Thus, a light-weight Wave-like system running on small wireless devices would be highly desirable in enabling them to achieve a high degree of coordination among themselves. However, before this step is taken, it is necessary to first investigate the suitability of using mobile agents to solve the dynamic ad-hoc network formation problem at the simulation level. We explain how the scatternet formation problem is explored from a mobile processing point of view in the next section.

4 Scatternet Formation through Mobile Processing

Our simulation of scatternet formation by mobile processing is based on a few assumptions. First, we assume that a routing/forwarding mechanism is already in place at every BD participating in the protocol; at the very least, BDs should possess some basic forwarding mechanism to relay data to neighbouring BDs. Another assumption is that mobile agents (Wave agents) must have access to the Host Controller Interface (HCI) in every BD in order to carry out the actual scatternet configuration. Such Wave agents can then make use of an Application Programming Interface (API) embedded into the BDs' middleware, ridding the need for the agent to carry additional code. In addition, a newly discovered BD does not need to be within radio range of every other BD in a pre-existing scatternet. This implies that on-demand (dynamic) scatternet configuration is supported. For now, BD mobility is not considered. Finally, our approach results in the dynamic configuration of scatternets that possess a tree topology.

A *master* node is potentially the busiest one in a piconet due to its inherent traffic controlling role, leaving little time to spare for other tasks. On the other hand, the period of time in which slave nodes wait for their scheduled access to the wireless channel can be used to discover new BDs. Thus, it is reasonable to expect that such newly arrived BDs would more likely be discovered by slave nodes in a given piconet. A similar consideration was pointed out in [18]. In such case, newly discovered BDs would have to assume a master role, leading to the almost uncontrolled creation of a new piconet every time a new BD is discovered. This situation is undesirable, as a higher number of piconets in a scatternet implies a larger number of hops (and thus a longer data transfer delay), as well as increased cluttering of the medium's bandwidth [3].

This is where the mobile processing solution comes into play. We start with a pre-existing piconet with at least two BDs. If a newly connected BD is discovered by a slave in this piconet, a mobile-agent-based reconfiguration process can be initiated to attempt topology optimization. Two specific circumstances are graphically depicted in Figure 2 where newly arrived BDs are shown as un-shaded masters. The one on the left hand is just within radio range of the existing master in Piconet 1, so a Wave agent is dispatched to alert the master of the newly discovered BD.

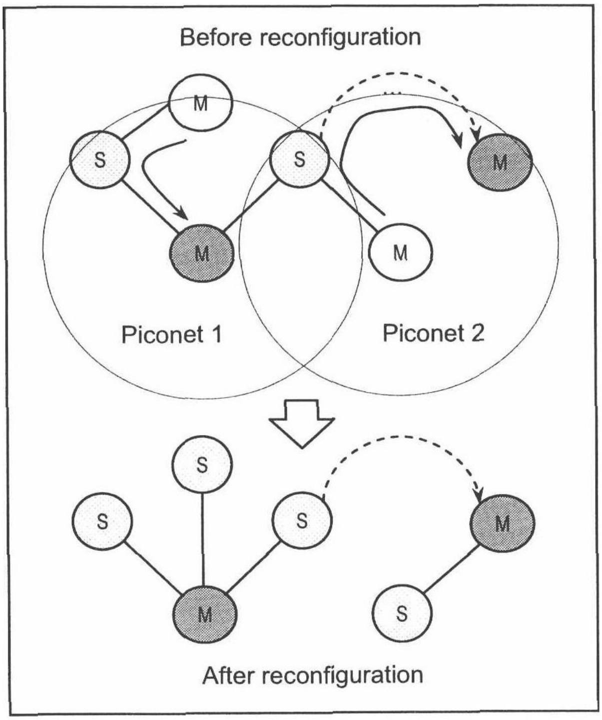


Fig. 2. On-demand scatternet configuration

In the second case, the new BD on the right hand is not within radio range of the master in Piconet 1, but within reach of the existing master in Piconet 2. The dashed arrow indicates however that there's no direct connection to such master; thus, Wave agents have to explore a longer route to reach the newly arrived BD in order to accomplish their objective.

In order for the previous scheme to work, Wave agents would have to carry the address of the newly arrived BD, along with the current value of its internal clock. Such information is sufficient for another BD to compute the current frequency hopping sequence of the new BD, allowing the targeted master node to synchronize with it, and thus enabling a subsequent paging process before entering the connected state [1].

The Wave system facilitates the implementation of a number of agent searching techniques that the user can employ to fit the needs of the system under development [15]. Of such techniques, an adequate one would be required to configure the scatternet when the second situation arises as explained in the previous example. For this first implementation, a breadth-first parallel-spread (BF-SS) searching technique is employed, in which agents coordinate a gradual breadth-first spreading of the mobile process. The difference between this modified scheme and the regular bread-first technique is that only one node is allowed to be active at a given time for every tier being probed, as described next.

The reconfiguration process is first attempted at the master of the slave that discovered the new BD. This can be accomplished by launching a Wave agent carrying the previously mentioned information about the new BD. A simple two-hop mobile agent forwarding is thus required before carrying out this initial probing, as shown in Piconet 1 of Figure 3. An unsuccessful probe causes the Wave agent to clone as many copies of itself as neighbouring piconets exist. The clone agents are then asynchronously forwarded to the masters located at subsequent tiers from the current location through (slave) bridge nodes. Once there, each individual clone agent signals its arrival to the same WI that launched it, which in turn acknowledges each agent's arrival in a sequential fashion. This operation is performed by means of the track layer of the Wave system. In this regard, the WI will automatically schedule an appropriate signalling scheme, depending on the way in which the agent's code has been structured. No explicit signalling command is required in the agent's code. Every agent is thus sequentially allowed to continue with its execution thread as scheduled by the preceding WI in the process. The actual radio proximity probing of the new BD can then be performed by computing its current hopping sequence using the BD-related information that each agent carries. The agent may then request access to the radio channel through the BD's HCI to enter the page state and perform the probing. When finished, the agent reports back the termination status of the probing process to the preceding WI.

Depending on the result obtained, the WI decides whether or not to continue with the process. An unsuccessful probe triggers a signal to the next scheduled agent. This enables every agent to continue in an identical manner as the previous one. The mobile process is recursively executed at subsequent piconet tiers, should all individual agents at the current tier return unsuccessful termination signals. The process stops upon finding a master who is able to both successfully page the newly arrived BD, and accommodate space within its piconet. When that happens, the new BD performs a master-to-slave role swap. The initial link between the new BD and the slave node that discovered it is finally broken, and a new link is setup to connect as a slave with the new master.

If no suitable master is found, a failure signal is propagated backwards to the original node that launched the first Wave agent. In this case, the whole process fails and the new BD keeps its master role. Clearly, employing a BF-SS technique ensures that no more than one master at a time will page the new BD, avoiding collisions on the medium. This is achieved by means of the enhanced Wave architecture that enables a superior coordination capability across a distributed network of Wave Interpreters. In addition, the BF-SS provides a bounded delay of the process completion time [19]. For details on the implementation of the BF-SS refer to [15].

5 Results

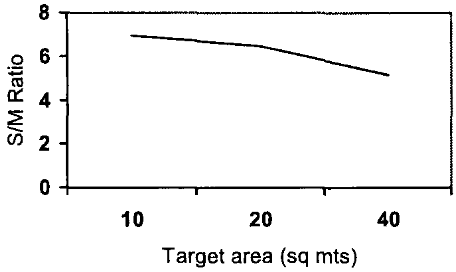
The scatternet formation scheme evaluated in this paper is based on an experimental Wave system available from [20]. Simulations comprise trial runs of 200 nodes arriving at uniformly distributed coordinates within test areas of 10, 20 and 40 square metres. For simplicity, the arrival of BD nodes is kept constant at rate of one per second, but other arrival random processes can be considered as well (say, Poisson).

Figure 3 shows the average results obtained for each of the areas being tested in the simulation. It can be observed that the target slave/master ratio achieved approaches a value of 7, the maximum targeted value (number) of active slaves per master in a given piconet. We also observe that such value degrades with the increasing size of the test area.

In addition, Figure 4 shows actual snapshots where test runs of 50 nodes were conducted. Figure 4a depicts a no-reconfiguration scheme, so that a newly arrived BD retains its original mode. An approximate 1:1 (26/24) slave/master ratio is achieved by such a scheme due to the randomness of the process.

Figure 4b shows a preliminary reconfiguration scheme where only the first tier from the current piconet is targeted. Visual inspection shows some noticeable improvement in the slave/master ratio (35/15= 2.33).

Finally, Figure 4c shows an n^{th}-tier reconfiguration scheme enabled by the BF-SS searching technique, where a clear improvement in the slave/master ratio can be observed (39/11 = 3.55).



Scatternet Size (m^2)	M/S Ratio
10 X 10	6.93
20 X 20	6.46
40 X 40	5.17

Fig. 3. Slave/Master ratio results

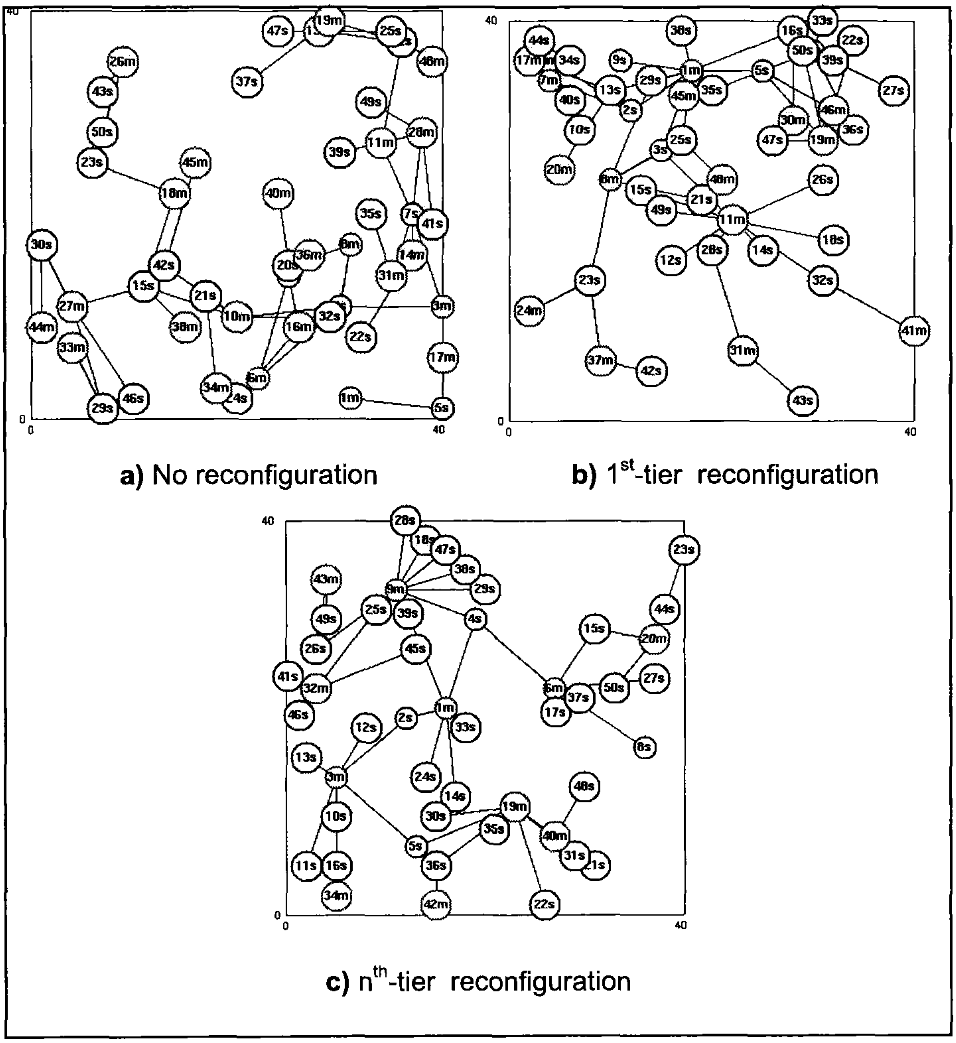


Fig. 4. Scatternet reconfiguration schemes