The Influences of Bridge Devices in a Scatternet Bluetooth

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***Abstract*—The Adaptive Frequency-Hopping (AFH) spread spectrum do a significant influence on the Bridge devices, responsible for the inter-Piconet communication. In Bluetooth, a Bridge must stop communicating within one Piconet and must change its frequency-hopping sequence for communication with another. We propose an update of a classical linear programming Bluetooth Scatternet formation model, penalising the activation of Bridges devices, by including new constraints. This new model produced a topology, coherent with a well-known Scatternet protocol. Our improved model has an ideal distribution of data flow and power consumption similar to a well-known Scatternet protocol, $O(\log n)$ time and $O(n)$ message complexity.**

***Keywords*—bluetooth; scatternet; fhss; centralised model.**

I. INTRODUCTION

The growth in sales and manufacturing of mobile devices is a fact. Much of this is due to the great popularity of smartphones and tablets, and the possibilities of direct communication. Faced with this reality, it is necessary to simulate new scenarios and propose innovative networking solutions using the low power network interfaces integrated in most marketed devices.

Developed with a focus on low cost and low power [1], Bluetooth allows to create spontaneous network applications in environments requiring little or no user interaction. The Bluetooth communication technique is the Adaptive Frequency-Hopping (AFH) spread spectrum, a Frequency-Hopping Spread Spectrum (FHSS) variation. The AFH causes some relevant side effects during the formation of wide networks, due the Bluetooth technology characteristics and constraints [2].

The Piconet was projected for short connections and communication with low power consumption. The Piconet does not communicate using a fixed channel; all its participant nodes have the same frequency-hopping sequence coordinated by a master node and should assume master or slave roles. There is only one active master in a maximum of seven slaves connected and all of the slave data stream passes and is controlled by it. The range of a Piconet is limited by the radio power of the master node; to expand its boundaries, we have the Scatternet. It consists of a set of Piconets interconnected by a Bridge node, transmitting messages between the master nodes [3].

The Bridges nodes are the bottleneck and had higher energy consumption nodes in a Scatternet. They are responsible for all inter-Piconet communication and constantly execute a frequency-hopping synchronisation with the master nodes, making possible the devices to exchange messages in a multi-hop ad hoc wide network scenario.

The distributed algorithms for Scatternets must deal with new challenges, such as, energy limits of the devices, the different roles assumed by the nodes of the Piconet (slave, master), the Bridge nodes, Piconet traffic centralised in master node, and Bluetooth bandwidth limits. Therefore, new routing algorithms proposals and strategies of control and coordination have to be inserted to get an efficient and implementable Scatternet algorithm into a real world. As shown by Miklos et al. [4] and Jedda et al. [5], the configuration of a Scatternet has impact on the performance of the network.

To the Scatternet, there are proposals of dynamic Bluetooth Scatternet Formation (BSF) and centralised models. BSF are protocols; centralised models are a optimization models that describe a Scatternet using linear programming.

As contribuition in this work, we proposed improvements to Marsan et al. [6] centralised Scatternet model. Penalising the activation of Bridge nodes, include new constraints. This new model produced Scatternet topologies more coherent with the ones predicted by Law et al. [7], a well-known $O(\log n)$ time complexity and $O(n)$ message complexity BSF dynamic algorithm.

Section II shows the related work. In Section III, we introduce the Scatternet and its models; Section IV presents the Bridge node and its influence in efficiency of a Scatternet. In Section VI, our contribution on improving the centralised model of Marsan et al. [6] is detailed. Finally, we detail the conclusions in Section VII.

II. RELATED WORK

The centralised model of Marsan et al. [6] provides a description of the Scatternet using linear programming. Its set of constraints are proposed in a min-max formulation resulting in a optimisation problem, solved by a centralised way. The objective is to obtain a optimal Scatternet topology that fulfils the traffic requirements and Bluetooth technology constraints, minimises the traffic load and energy consumption of the master and Bridge nodes. Therefore, this model does consider the side effects of Bluetooth frequency-hopping communicating, such as: excessive delay discovery of new nodes phase [8] and the frequently frequency resynchronisation efforts of Bridge nodes, necessary for inter-Piconets message transport.

In Law et al. [7], a new dynamic algorithm of Scatternet formation is introduced. The protocol is presented in a two-layer approach:

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1) How the devices are organised into Scatternet;
2) How the devices can discovery each other with efficiency.

The devices are organised by sets of interconnected devices, called components, and these can be a simple device, a Piconet or a Scatternet. Each component has a leader and executes the MAIN procedure in the beginning of each round. In MAIN, the leader calls SEEK procedure with probability ($\frac{1}{3} < p < \frac{2}{3}$) and SCAN procedure. This ensures that in each component, there is at least one device performing these functions. When a leader performs SEEK it tries to acquire new slaves performing SCAN. When a device in SEEK finds a device in SCAN, the CONNECTED procedure is called, and a new link is established with the component. The reorganisation of Piconets happens by one of three operations: MOVE, MERGE, MIGRATE, and these operations ensure that each new and larger components have only one leader to coordinate the distribution of devices. The Scatternet formed by this protocol is proved $O(\log n)$ time complexity and $O(n)$ message complexity, and has the following properties:

- Any device is a member of at most two Piconets;
- The number of Piconets should be optimal, and the number of Piconets lower bound is $\lceil (n-1)/k \rceil$, being that n the number of network nodes and k the number of slaves in a Piconet.

Jedda et al. [8] analysed the impacts of changing Bluetooth parameters on the static and dynamic Scatternet formation protocols. These parameters are related to the use of the frequency hop communication technique. The Scatternet formation on static protocols happens as follows; each node alternates randomly between the **INQUIRY** and **INQUIRY SCAN** Bluetooth discovery states, when one device discovers each other, a temporally Piconet is formed until being destroyed at the end of the communication. They called this mechanism of *ALTERNATE*; see BlueStars [9]; BlueMIS [10] and BlueNet [11]. In dynamic Scatternet protocols, the discovery phase is interlaced with the network formation; the node shares its time between discovering new devices and communication in the Scatternet. The examples of dynamic protocols are: Law et al. [7] and Cuomo aet al. [12]. Jedda et al. [8] using the ns-2 [13] simulator, found that changing parameters of Bluetooth 1.2 discovery phase produces *ALTERNATE* Scatternets 3.5 times faster.

In [14], the constraints of the centralised model of Marsan et al. [6] are complemented by new discussions.

- The fact that increasing the number of Piconets that form the Scatternet hasn't benefits to the network throughput, because Bridge nodes become the communication bottlenecks;
- A discussion and proposal of a distributed algorithms in Scatternet formation, including routines for the insertion and removal of nodes.

III. SCATTERNET

The Scatternet extends the limits of a Piconet, 7 slave nodes communicating in the range of a master node coordinator, making possible a wide network using Bluetooth devices. They are collections of Piconets formed spontaneously without need of fixed infrastructure. Its coordination is complex because there is a need to cross multiple Piconets, in search of the destination and handle multiple alternate paths and cycles, following the Piconet constraints, Soares et al. [15].

Bluetooth specification does not provide details about Scatternets, and leaves open to new protocol propositions. Distributed algorithms are needed to start a Scatternets. In turn, we have different routing strategies and initialisation. These topological characteristics directly influence the flow of data over the network and energy consumption of devices.

Some examples of the challenges in creating Scatternets models:

- The need to coordinate different roles of the devices (slaves, masters and Bridges) to form a Piconet;
- Energy limitations of mobile devices;
- The low data rates of Bluetooth;
- The excessive delay during the Piconet start-up, because the side effects of AFH during the discovery of devices [15];

In the literature, we can find studies of dynamic and centralised Scatternets models.

III-A. Dynamic Model

Scatternet dynamic models are protocols, and its distributed algorithms use the following heuristic [3]:

- Any device is a member of no more than two Piconets; the number of Piconets is close to the optimal; the lower bound of Piconets is $(n-1)/k$, n being the number of network nodes and k the number of slaves in a Piconet;
- Bridge devices should never be masters. This reduces the load Scheduler of the masters, which will then only consider the intra-Piconet communication;
- The number of Piconets is restricted. This reduces the number of potential inter-Piconet conflicts in the Bridges, but limits the potential of alternative routes;
- There should be as few Piconets as possible. This reduces the number of channels to be used and thus potential interference;
- Piconets should not be connected to more than one Bridge. This minimises the coordination effort needed for Scheduling;
- A device must participate in as few Piconets as possible. This decreases the amount of inter-Piconet Scheduling in the device.

To represent a Scatternets topology, we use graph representation. It shows all the possible connections between the devices in range, and the most common Scatternet algorithms and your topologies represented by graphs are:

Trees:

- It is represented by a connected graph without cycles;
- Uses minimal edges for connection;
- There is no alternative route search between nodes;
- It is more susceptible to broken links during loss of connection or power failure of a device;
- Have more simplified routes, as there is only one possible path between nodes;
- Have a more simplified routing;
- Reduces contention in the transmission slots in TDD, thus are less susceptible to the side effects of Frequency Hopping [3];
- A minimum of Piconets is desired, making the Bridges we participate in a maximum of two.

UDG:

TABLE I. SCATTERNET PROTOCOLS

Index	Protocol
1	BlueStars
2	BlueMesh
3	Scatternet via Insertion and Removal of Nodes
4	BlueRings
5	Distributed Scatternet Formation Procedure (DSFP)
6	Simple Scatternet Formation
7	Scatternet via Merge, Movement and Migration
8	Scatternet Formation based on Partial Triangulation
9	BlueRing Trees
10	Scatternet Formation via grouping
11	Scatternet Formation Maintenance Extension
12	Topology Construction Protocol for Bluetooth
13	BlueTree Auto-Routing
14	Tree Scatternet
15	BlueNet
16	Blueroot and Distributed Bluetrees
17	BlueStar Islands

- An edge is defined if their Euclidean distance is greater than one;
- The graph is formed as the nodes come close.

1-Factor:

- $(n = 2)$ is expected where n is the number vertices of Piconet;
- An edge is always a set slave master.

Ring:

- The Scatternet are called Bluerings [3];
- Each device belongs and two Piconet and has two links in total; each device is master and slave at the same time;
- Supports a maximum of 2 active links; route is simplified because the packets are simply forwarded;
- A large ring can get a big delay resynchronisation, proportional to the number of Bridges.

III-A1. Scatternet protocols

The Scatternets protocols are treated as a finite state machine by most the authors [3]. They are built as mechanisms to control the relationship between the states defined by specif cation Bluettooth: **INQUIRY, INQUIRY SCAN, PAGE, PAGE SCAN,** and these states are alternate and coordinated. Some protocols also use the information for each device, such as battery capacity, type of mobile device and capacity data flow, resulting in a variety of Scatternets topologies, each with a characteristic optimisation. Table I lists the types of Scatternet protocols.

III-B. Centralised Model

The centralised model of Scatternet, also known as the static Bluetooth Scatternet model, is not a protocol. Instead, it provides a description of the Scatternet formation using mathematical programming, and constraints are proposed in a min-max formulation, leading to an optimisation problem which is solved in a centralised way. It can find the best possible performance for a given graph, obeying the Piconet Bluetooth restrictions. The objective of this model is to minimise the traffic of nodes that are subject to greater congestion and energy consumption, such as the masters and Bridges, respecting the restrictions following the full convergence of the Scatternet. After that, it can be used to generate a Scatternet formation.

For instance, the Marsan et al.'s [6] model discusses the centralised Scatternet requirements:

- Network Connectivity: there must be at least one path between two nodes in the network;
- System Complexity: in order to reduce the complexity of the network, the number of Piconets is limited to a fixed value;
- Traffic Demand: the network must support the necessary source-destination connection;
- Roles of the Node: there must be some constraints applied to some nodes, according to the role they play: master or slave.

The constraints and requirements used in this model are:

- network structure;
  - Active nodes participants of Piconet can not be greater than 8;
  - Two devices to communicate must be in the range of the other;
  - A node can only be master in a Piconet;
- system capacity: The maximum bit rate of a Piconet will equal to 1 Mbps;

IV. BRIDGE NODES

Bridges are the elements that enable multi-hop communication across the Scatternet. They are needed for inter-Piconet communication. They alternate the pattern of frequency hopping among those masters connected. The Bluetooth mode that defines this operation is the HOLD mode. This Bluetooth state is used as a solution for the coexistence of a node in more than one Piconet. During this mode the device participates in different Piconets using a Time Division Multiplexing (TDM) technique. In the Scatternet, they are implemented in two types, namely, slave-slave and master-slave.

The Bluetooth HOLD mode is used to release a connection device active with the master. During this mode, a device already connected to Piconet, can sleep for a short time allowing the master node communicate or check for new devices, this communication is called inter-Piconet.

During transport of inter-Piconets messages, the Bridge device, common to the Piconets, goes to HOLD mode. This mode allows it to switch contact among the Piconet's masters, during this process, the Bridge node needs a frequency hopping synchronisation with Piconet that wants to communicate. For this to happen, the Bridge changes its pattern of frequency hopping and begins to hear the master polls messages waiting for the moment that it may send messages from other Piconet.

Some Scatternets protocols use Bridge nodes master-slave type. This type has some limitations and performance issues. As a Piconet can only have one active master, the Bridge node that acts as the master of a Piconet and slave of the other, need to leave temporarily Piconet that acts as the master, without coordination, to be able to forward messages to another. This process has a high cost of resynchronisation, since it occurs in one of Piconets a temporary loss of its master. For most applications, this cost of excessive synchronisation prevents the use of Bridges nodes master-slave type for some Scatternets applications.

The message transport procedure between Piconets has high resynchronisation cost. The need for hopping pattern of trade of Bridge us with their masters, adjustments speed

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and procedures for inter-Piconet scheduling to coordinate activities itinerant devices, cause this process an overhead due to the guard time slots. This is because during the exchange of communication inter-Piconet using two time slots, which during this process are unavailable for communication. These characteristics of Bridges directly influence the performance of Scatternet, as are energy consuming bottleneck points and traffic [3].

IV-1. Inter-Piconet Schedulling

In the Scatternet, to coordinate communication of Bridges algorithms, inter-Piconet scheduling is necessary. These algorithms enable the Bridge be available for communication when the master need it. They use a common solution to solve this problem, reserve slots for communication with the Bridge. These reserved slots are called Rendezvous Points (RP). Intra-Piconet Scheduling algorithms have a common feature, namely, the requirement to choose the slots and control of RP. We can list some of the approaches of inter-Piconet Scheduling [3] and protocols that deal with the rendezvous windows.

- Maximum Distance Rendezvous Point (MDRP);
- Adaptive Scheduling using a max-min RP;
- Flexible Scatternet Scheduling (FSS)
- Adaptive Presence Point Density (APPD)
- Pseudo-Random Coordinated Scatternet Scheduling (PRCSS), uses pseudo-random sequence of RP;
- Locally Coordinated Scheduling (LCS)
- QOS, the Scheduling is seen as an optimisation problem, an analysis of capacity occurs before the spread of the routes;
- Load Adaptive Algorithm (LAA), this algorithm, determines the duration of the activities Bridges of each Piconet;
- Proposal of a new JUMP mode, this new mode already has specific rules to coordinate the communication of Piconets;
- Scheduling interference analysis;
- Scheduling by analysis of theoretic queue;

IV-2. Influence of Bridge nodes in efficiency of a Scatternet

The number and position of Bridge nodes are critical for the efficiency evaluation of the resulting Scatternet topology. They are responsible for inter-Piconet communication, and are subjected to greater communication and processing overhead than other nodes.

To act as a Bridge, a Bluetooth node goes to HOLD mode; it is necessary to inter-Piconets communication. During its mode, the Bridge node awaits polls package of the masters, for the destination of messages; it have a high energy cost, because in this procedure, the device receives a computational effort of intra-Piconet Scheduling algorithm and its strategies to handle with the RP.

An efficient Scatternet topology should have a minimum number of Bridge nodes because:

1) Few Bridges means less delay for messaging between the Piconet, and less coordination effort with the master nodes;
2) A smaller number of masters in the Scatternet results in less Piconets and Bridge nodes; consequently, less synchronisation with the master nodes and performance influences of the algorithms inter-Piconet Scheduling.

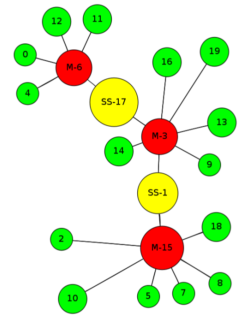

Figure 1. Common Scatternet of 20 devices found by simulation

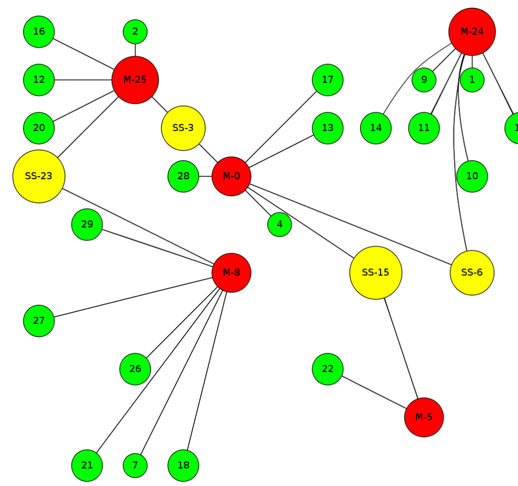

Figure 2. Common Scatternet of 30 devices found by simulation

V. TOPOLOGY ANALYSIS

To check the Scatternet topologies that would be found, we chose a dynamic and a centralized model.

V-A. Dynamic Model

To check the Scatternet topologies that would be found using a dynamic model, we chose the Law et al. [7] algorithm to simulation. This algorithm fits in item 7 of Table I, and Scatternets resulting from the simulation have $O(\log n)$ time complexity and $O(n)$ message complexity. Using ns-2 [13] with UCBT [16] extension, we simulated 30 Scatternet instances of 20 and 30 devices. With the simulation results, we generated the graph of the most common Scatternet topology found with 20 devices, in Figure 1 and with 30 devices in Figure 2.

The topology of these graphs follow the efficiency rules proposed in Section IV-2 and used by the algorithm Law et al. [7]. The red nodes are the Piconet masters M, the yellow are Bridge nodes type slave-slave (SS) and green nodes are the Piconet slaves.

V-B. Centralised Model

To find the Scatternet topologies resulting of centralized model of Marsan et al. [6], we follow the description of its

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TABLE II. MARSAN ET AL. [6] SCATTERNET CONSTRAINTS

Constraint	Description
1	a node is either a master, or a slave or a Bridge;
2	a slave is assigned to one master at most;
3	a slave or a master are assigned to one Piconet at least; while a Bridge is assigned to two Piconets at least;
4	a master is assigned to it-self;
5	maximum connect distance is Z_{MAX};
6	limits the size of Piconet to X_{MAX};
7	If nodes i and j are masters; the assignment of i to j if is assigned to i;
8	prevents cycles among sets of three nodes;
9	the maximum number of masters is M_{MAX};
10	nodes in M to be masters;
11	nodes in set V to be slaves.

model:

The model from Marsan et al. [6] is described as follows:

- N - Number of nodes;
- C - Connections through network;
- M_{MAX} - Maximum Piconets;
- X_{MAX} - Maximum number of active nodes in Piconet;
- Z_{MAX} - Maximum radius of Piconet.
- M - Nodes constrained to act as masters;
- V - Nodes constrained to act as slaves.

For each node i, $i \in N$, three binary variables are defined: μ_i,β_i, and σ_i:

- μ_i, is equal to 1 if the node is a master and 0 otherwise;
- β_i is equal to 1 if the node is a Bridge and 0 otherwise;
- σ_i is equal to 1 if the node is a slave and 0 otherwise;

For each pair of nodes $(i, j), i, j \in N$, the set $X = \{x_{ij}\}$, x_{ij} is 1 if j is assigned to master i, otherwise 0 .

The model has the following constraints, described in Table II :

$$\mu_i + \beta_i + \sigma_i = 1, \quad \forall i \in N \tag{1}$$

$$\sum_{i \in N} x_{ij} \leq \sigma j + |N|.\beta_j + |N|.\mu_j, \quad \forall j \in N \tag{2}$$

$$\sum_{i \in N} x_{ij} \geq 2 - \sigma j - \mu_j, \quad \forall j \in N \tag{3}$$

$$x_{ii} = \mu_i, \quad \forall i \in N \tag{4}$$

$$x_{ij}.z_{ij} \leq Z_{MAX}.\mu_i, \quad \forall i, j \in N \tag{5}$$

$$\sum_{j \in N} x_{ij} \leq X_{MAX}.\mu_i, \quad \forall i \in N \tag{6}$$

$$2 + x_{ji} \geq \mu_i + \mu_j + x_{ij}, \quad \forall i, j \in N, \quad i \neq j \tag{7}$$

$$x_{ik} + x_{jk} \leq 4 - \mu_i - \mu_j - x_{ij}, \forall i, j, k \in N, i \neq j, j \neq k \tag{8}$$

$$\sum_{i \in N} \mu_i \leq M_{MAX} \tag{9}$$

$$\sum_{i \in M} \mu_i = |M| \tag{10}$$

$$\sum_{i \in V} \sigma_i = |V| \tag{11}$$

These requirements and restrictions lead to a min-max criterion that can be solve using the CPLEX solver [17].

In Marsan et al. [6] paper, to resolve a 20 devices Scatternet topology, we used the input parameters of Table III and the resulting graph is represented by Figure 3.

TABLE III. 20 DEVICES SCATTERNET - INPUT PARAMETERS

N	C	M_{MAX}	X_{MAX}	Z_{MAX}	M	$\|V\|$
20	15	4	8	$\frac{10\sqrt{2}}{3}$	$\{7, 17\}$	0

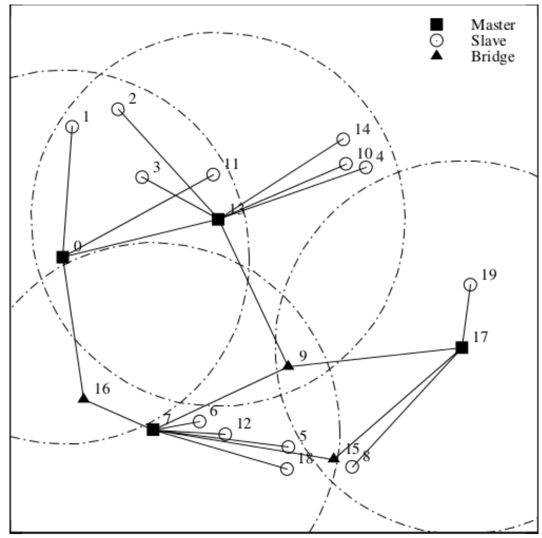

Figure 3. 20 devices Scatternet topology found in Marsan et al. [6]

TABLE IV. 30 DEVICES SCATTERNET - INPUT PARAMETERS

N	C	M_{MAX}	X_{MAX}	Z_{MAX}	M	$\|V\|$
30	4	8	8	$\frac{10\sqrt{2}}{3}$	$\{5, 25\}$	0

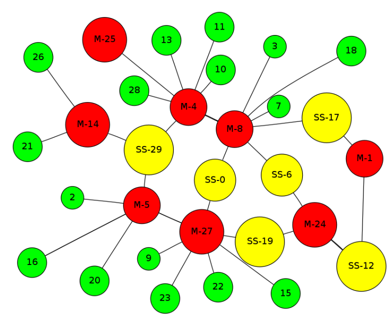

Figure 4. 30 devices Scatternet topology, found using the Marsan et al. centralised model

To resolve a 30 devices Scatternet topology with Marsan et al. centralised model, we use the input parameters of Table IV and the resulting graph is represented by Figure 4.

In the graph shown in the Figure 3, that represents the topology found how solution in the Marsan et al. [6] model, we can observe that some of the items that influence the performance of a Scatternet are neglected:

- The connection between master node 13 with node 0, is a link master / master, this setting is not possible to a Bridge node;
- Node 9 is the Bridge of three Piconets, a prohibitive result, due to the high cost of coordination with the masters conforms addressed in Section IV-1;
- We observe various network loops between the Pi-

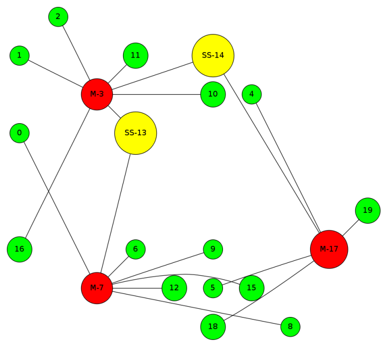

Figure 5. 20 devices Scatternet topology, found with our centralized model

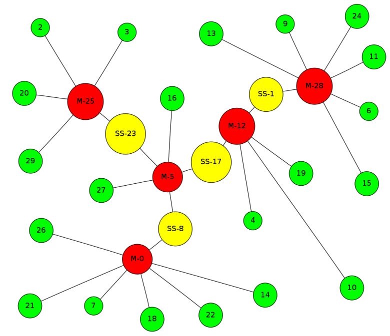

Figure 6. 30 devices Scatternet Topology, found with our centralized model.

conets of masters 7 and 17, connected by nodes 9 and 15, this increase the complexity of a Scatternet, being necessary the implementation of processing loops together with algorithms, such as the spanning tree;

- Four Piconets is an excessive amount for 20 nodes, according to Piconets lower bound proposed by Law et al. [7] and presented in Section III-A, this number should be three;

We observe that the 30 devices Scatternet topology resulted by centralised model of [6] shown in Figure 4, has the following items that influence its performance:

- The connections between nodes 4 and 25, 27 and 5, 8 and 4, are master-master links, this setting is not possible to a Piconet;
- 8 Piconets and 6 Bridges are too many for a Scatternets of 30 devices, according to Piconets lower bound proposed by Law et al. [7] and presented in Section III-A, this number should be five;

VI. Improving the Centralised Model

To get topologies similar to Scatternet protocols, the optimization models, such as Marsan et al. [6], must be improved. We added penalties to the Bridge nodes and these new constraints:

- $\mu_i + \mu_j + x_{i,j} \leq 2 \quad \forall\ i,j \in N \quad i \neq j$ **; a master must only belong to one Piconet.**
- $\beta_i + x_{ij} + x_{ji} + x_{ik} + x_{ki} + x_{kl} + x_{lk} \leq 3 \quad \forall i,j,k,l \in N \quad i \neq j \vee i \neq k \vee i \neq l \vee j < k \vee k < l$ **; a Bridge must only connect two Piconets.**

By adding penalties in Bridges and these two new constraints, we can say that the resulting graph of the solution is less prone to the effects of topology coordination delays Bridge node, responsible for inter-communication Piconet.

In order to evaluate our proposal, we use as an example the instance originally used by [6] represented by Table III and the graph of Figure 1.

We note that the Scatternets topology found with the solution of these parameters for our model, represented by graph in Figure 5, follows the heuristic of a Scatternet dynamic protocol discussed in III-A, and respects all the items needed for a efficient Scatternet discussed in Section IV-2.

In our solution, 3 masters in 3 Piconets and 2 Bridges were found, which is the same topology found by simulation of a Scatternets of 20 devices using the protocol [7] represented by Figure 1.

These results are significant because the algorithm [7] has a cost $O(\log n)$ time complexity and $O(n)$ message complexity. Given this result, we can say that the resulting graph of our model is one Scatternet with ideal distribution data flow and energy consumption.

To validate our centralised model in larger Scatternet, we use the input parameters of Table IV. The solution of a 30 nodes Scatternet topology is represented by Figure 6.

The Scatternets found by our model has the same topology of graph Figure 2 formed by the dynamic model [7], 5 Masters in 5 Piconets and 4 Bridges. This topology follows the lower bound of Piconets proposed by [7], and has the fewest possible Bridges.

Comparing with the results of the original model from Figure 2 with the graph of our solution Figure 6, we can see fewer Piconets, 5 against 8 of the original model, fewer Bridges, 4 against 6 of the original model. Table V and Table VI summarizes our results in a comparison with the topologies found in Scatternet models, namely, centralised, dynamic and our centralised model, respectively.

TABLE V. 20 DEVICES SCATTERNET - TOPOLOGY

Model	Piconets	Bridges	Piconets over the bound
Marsan et al.	4	3	1
Law et al.	3	2	0
Soares et al.	3	2	0

TABLE VI. 30 DEVICES SCATTERNET - TOPOLOGY

Model	Piconets	Bridges	Piconets over the bound
Marsan et al.	8	6	3
Law et al.	5	4	0
Soares et al.	5	4	0

VII. Conclusion and Future Work

In a scatternet, Bridges are actually points of greatest loss of efficiency because they are the nodes responsible for the coordination of inter-Piconet packet traffic. The computational effort of this process makes them network bottlenecks and points of higher power consumption by definition.

The centralised model that uses mathematical programming is useful in evaluating the performance of the simplest Scatternet topologies. In adapting the classic model of Marsan et al. [6] by changing the weights of the Bridges and adding new constraints, we achieved results similar to those obtained by simulation of dynamic algorithm.

In addition, we can conclude that our resulting graph of the static Bluetooth Scatternet model represents a Scatternet with an ideal distribution of data flow and power consumption, since its result is similar to that of Law et al. [7]: complexity of $O(\log n)$ time complexity and $O(n)$ message complexity.

In ours solution, the topology found is coherent with the rules of efficiency of a Scatternet protocol, minimizing the several performance problems related to the positioning and number of Bridges.

In future works, we will propose a dynamic Bluetooth Scatternet Formation protocol that considers the impact of frequency-hopping in the Bridge nodes and inter-Piconet scheduling.

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