Multi AP Concepts for SCO Traffic in a Bluetooth Based Radio Infrastructure Network

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Abstract – **In this paper, we consider a radio infrastructure network (RIN), which consists of Bluetooth Access Points (APs) to provide services to ad hoc users. The RIN inherently supports both voice and data connectivity. Since Bluetooth offers the establishment of Synchronous Circuit-Oriented (SCO) traffic, the concept under study features a low-cost alternative to indoor cellular base stations. However, a single AP can serve a maximum of only three SCO channels and may not be capable of satisfying the voice traffic demands in hot spots. In order to offer more bandwidth in a location with high voice traffic, two or more APs may be placed in the same coverage area. Respective AP clusters will be denoted as Multi APs. Three Multi AP concepts for doing the SCO allocation are presented and discussed. Our findings show that employing Multi APs significantly reduces the blocking probability.**

Keywords: Radio infrastructure network; Bluetooth; access point; synchronous circuit-oriented traffic; Erlang model; blocking probability.

1. INTRODUCTION

In this paper, we consider a radio infrastructure network (RIN) designed to provide multimedia connectivity and wireless Internet using the Bluetooth technology [1-5], see Section 2. This wireless local area network (wLAN) consists of Bluetooth Access Points (APs), which offer services to ad hoc users, and it inherently provides both voice and data connectivity. As Bluetooth offers the establishment of Synchronous Circuit-Oriented (SCO) traffic, the concept under study features a low-cost alternative to indoor cellular base stations. In contrast to standard wLANs, voice connections receive some level of premium service through guaranteed bandwidth in reserved channels, while data uses the remaining capacity.

Since such a RIN contains several APs, the question on how to allocate the SCOs to the APs arises. Furthermore, a single AP can serve a maximum of only three SCO channels and hence may not be capable of satisfying the voice traffic demands in hot spots with a large number of users. Therefore, we propose to deploy Multi APs for those particular locations instead of only a single AP. Three Multi AP concepts for doing the SCO allocation are presented and discussed in Section 3. A performance study is presented in Section 4 along with a simple dimensioning rule for the number of APs to obtain a desired call blocking behavior. Finally, Section 5 summarizes the paper and indicates some future work.

2. THE RADIO INFRASTRUCTURE NETWORK

The considered RIN consists of a three-tier topology as follows (Fig. 1). The APs are located in tier 1 and have the ability of supporting up to seven active units or mobile terminals (MTs). Each AP is connected to a cluster controller (CC) where a CC may control up to six APs. These controllers constitute the second tier and have the tasks to establish, monitor and control device connections as well as data flow. Finally, CCs are connected through a wired or wireless backbone to a Gateway (GW), which establishes the third tier. Tasks of a GW include management, service functions, and centralized control over the traffic within the network. It also may route traffic flow to and from an external fixed or mobile network. The small cell sizes of about 10m radius, coupled with data rates up to 723.2kbps, allows high, non-interfering data densities, something not possible with the large cells in mobile cellular networks. Furthermore, the examined RIN will offer flexible platforms to support service diversity, and rapid deployment of new wireless services.

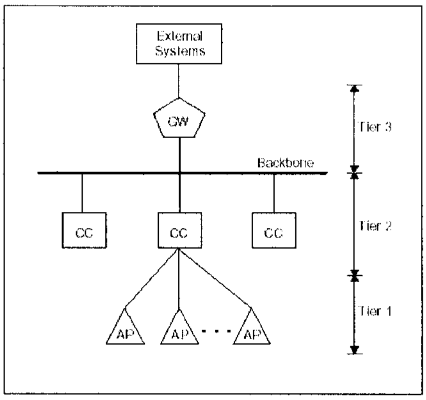

Fig. 1. Topology of the considered radio infrastructure network.

3. Multi AP Concepts for SCO Traffic

The utilization of SCO channels in applications, which have a large user penetration, such as experienced in shopping centers, open office space or other hot spots, is crucial for maintaining a certain level of quality of service (QoS). The allocation of one AP connection to SCO traffic decreases the available bandwidth for asynchronous connectionless (ACL) traffic. It also decreases the ability to find new potential units to communicate with and to be discovered by a scanning unit.

In order to offer more bandwidth in a particular hot spot location, two or more APs may be placed in the same coverage area preferably in close proximity to reduce installation costs. Respective scenarios will be called hereinafter as Multi AP concepts. A central unit (CU) may be employed to manage and control a Multi AP cluster within the allocated coverage area. For example, the CU may monitor APs, which perform inquiry scan, to schedule cases where the call establishment terminates in scan mode.

A fundamental feature of all the proposed Multi AP concepts for SCO traffic in the Bluetooth based RIN is that always at least one Bluetooth unit should scan for MTs. In the presented alternative concepts, an AP can stay in scan mode and either of four groups as follows:

SCAN MODE: Unit performing inquiry scan.

IDLE 3: Unit with all three SCO channels available.

IDLE 2: Unit processing one voice call.

IDLE 1: Unit processing two voice calls.

FULL: Unit processing three voice calls.

Subsequently, we will detail the three alternative concepts, which basically differentiate by the strategy of moving APs between the various modes or groups. Note that modes or groups may be regarded as states. Thus, a state diagram can be used to visualize the relationship between states where the states are connected via directed branches. Branches will be labeled with numbers to facilitate description of the events causing a state transition.

3.1 Concept 1

This approach is based on the strategy that an AP is kept in SCAN MODE until all three SCO channels have been occupied. Once this event has taken place, this AP will move into the FULL state. The AP may transfer from FULL to IDLE 1, IDLE 2 or IDLE 3 depending on the subsequent completion of one, two or three voice calls, respectively. Other possible state transitions are indicated in the state diagram shown in Fig. 2a along with an example of a state reservation sequence shown in Fig. 2b. Particular features of concept 1 are as follows:

IDLE 3: APs having all three SCO channels idle are placed in this group. The CU picks one AP from a queue in the IDLE 3 group to enter SCAN MODE, which is then detectable by an MT (1). The AP stays in the IDLE 3 group until all three SCO channels are occupied and then moves to the FULL group (2). This procedure will continue until the entire IDLE 3 group is empty. Subsequently, APs from first the IDLE 2 group and then the IDLE 1 group may be selected from the respective queues to enter the FULL group. If no APs are in either of the IDLE groups, the system is blocked.

IDLE 2: APs having two SCO channels idle are placed in this group. If a call ends, the serving AP is moved to the IDLE 3 group (6). In case the IDLE 3 group is empty and no AP is in SCAN MODE, an AP from the IDLE 2 queue will be selected to enter the SCAN MODE (7).

IDLE 1: APs having one SCO channel idle are placed in this group. If a call ends, the serving AP is moved into the IDLE 2 group (4). In case the IDLE 2 and IDLE 3 groups are empty and no AP is in SCAN MODE, an AP from the IDLE 1 queue will be selected to enter the SCAN MODE (5).

FULL: APs having no idle SCO channels are placed in this group. If a call ends, the serving AP is moved into the IDLE 1 group (3). If all APs reside in the FULL group, all new calls will be blocked.

An advantage of concept 1 is that only a minimal amount of signaling is required between an access point and the central unit. The CU is only required to activate an additional AP once the current AP serves three SCO channels. A drawback of this concept is that an active AP can spend less time in the SCAN MODE to perform an inquiry scan of new MTs when one or more SCO connections are being served. Also, data devices that are connected to one specific AP may run out of capacity.

3.2 Concept 2

This concept addresses the problem that connection establishment performance is degraded if one or more SCO channels of an AP are occupied. The goal is to load the APs as symmetrically as possible. The concept is based on a strategy that an AP moves from SCAN MODE to an IDLE group, as soon as communication with an MT is initiated. Simultaneously, an AP with preferably more idle SCO channels moves into SCAN MODE. Possible state transitions are indicated in the state diagram shown in Fig. 3a along with an example of a state reservation sequence shown in Fig. 3b. Particular features of concept 2 are as follows:

IDLE 3: APs having all three SCO channels idle are placed in this group. The CU picks one AP from a queue in the IDLE 3 group to enter SCAN MODE (1). Once this AP has been detected by an MT or found by an MT, it will be moved into the IDLE 2 group (2). Simultaneously, a new AP from the IDLE 3 group moves in SCAN MODE (1).

IDLE 2: APs having two SCO channels idle are located in this group. If no APs are left in IDLE 3, the CU picks an AP from the IDLE 2 group to enter SCAN MODE (3). Once this AP has been detected or found by an MT, it will be moved into the IDLE 1 group (4). Simultaneously, a new AP from the IDLE 2 group will move in SCAN MODE (3). If a call is finished, the respective AP moves back into the IDLE 3 group (5).

IDLE 1: APs having one SCO channel idle are placed in this group. If no APs are left neither in the IDLE 3 nor the IDLE 2 group, the CU picks an AP from the IDLE 1 group to enter SCAN MODE (6). Once this AP initiates communication with an MT it moves into the FULL group (7). Simultaneously, a new AP from IDLE 1 moves into SCAN MODE (6). If a call is finished, the respective AP moves into the IDLE 2 group (8).

FULL: APs having no idle SCO channels are placed in this group. If a call ends, the serving AP is moved into the IDLE 1 group (9). If all APs reside in the FULL group, all new calls will be blocked.

An advantage of concept 2 is that the mean time to connect can be expected to be shorter compared to concept 1. However, a more sophisticated scheduler in the CU may be recommended.

3.3 Concept 3

This concept also addresses the problem of performance degradation in connection establishment if one or more SCO channels of an AP are occupied. Similar as concept 2, it is based on the strategy that an AP moves from SCAN MODE into an IDLE group, as soon as communication with an MT is initiated. In addition, it allows more than one AP to reside in the SCAN MODE. This further reduces mean time to connect using an appropriate scheduler in the CU. State diagram and state reservation sequence are similar to those for concept 2.

Additional requirements for a CU include the following:

- CU must be able to control individual APs in a Multi AP,
- Monitor number of calls being processed by each AP,
- Insure that sufficient number of APs are in SCAN MODE,
- Select AP that shall enter SCAN MODE.

Fortunately, the Bluetooth specification provides a Host Controller Interface (HCI) along with a set of HCI commands. Especially, commands such as [1-2]

- HCI_Write_Scan_Enable
- HCI_Write_Inquiry_Scan_Active
- HCI_Write_Page_Scan_Activity
- HCI_Switch_Role
- HCI_Add_SCO_Connetion
- HCI_Disconnect

may be used to implement the above CU requirements.

4. PERFORMANCE CHARACTERISTICS

The performance calculations are based on the well-known Erlang model that has been proven to be applicable for voice traffic. In particular, we may use the Erlang loss model to calculate the blocking probability for the various Multi AP concepts. We assume that call arrivals and service time are exponentially distributed. The number m of servers in the assumed queuing system i.e. number of SCO channels, is a multiple of three.

Then, the call blocking probability can be expressed as [6]

$$p_m = E_m(\rho) = E_m\left(\frac{\lambda}{\mu}\right) = \frac{\dfrac{\rho^m}{m!}}{\displaystyle\sum_{k=0}^{m} \frac{\rho^k}{k!}} \qquad (1)$$

where ρ, λ, and μ, respectively, denote the utilization, arrival intensity in calls per hour, and service intensity in calls per hour. The carried traffic in Erlang can be written as

$$Y = A \cdot [1 - E_m(\rho)] \tag{2}$$

where A denotes the offered traffic in Erlang.

First of all, let us consider the case that the numbers of APs and holding times are given. The corresponding blocking probabilities are shown as functions of arrival intensities (Table 1). As can be seen from Table 1, the blocking probability can be significantly reduced by employing Multi APs with three or six APs compared to the case of only a single AP. For example, an arrival intensity of 1000 calls per hour with service time of 1 minute each results in a blocking probability of 83% for 3 channels in a single AP scenario but can be dropped to 13% when a Multi AP with 18 channels is used. Although an arrival intensity of 1000 calls per hour is rather high for a Bluetooth cell radius of 10m (Power class 3), the example indicates that the use of 6 cooperating APs with 18 channels may be sufficient for serving a high load.

To further explore improvements of Multi APs on the blocking probabilities, one may consider adding several such clusters together with each Multi AP (MAP) comprising six Bluetooth units. The corresponding performance is depicted in Fig. 4. For example, if the offered traffic is 75 Erlang, the one MAP case would have a blocking probability of 76% compared to 1% in case 5 MAPs were employed in the same coverage area.

Now, we specify a blocking probability objective or Grade of Service (GoS) and the offered traffic. A simple dimensioning rule for the number of APs needed to maintain a specific GoS can be based on the resource allocation law [7]

$$N(Y) = k_0 + k_1 Y + k_2 Y^{k_3} \tag{3}$$

where N represents the number of required channels, Y is the carried traffic according Eq. (2) and k_0, k_1, k_2, and k_3 are coefficients. It has been shown in [7] using a genetic algorithm that for a blocking probability of 1%, the coefficients should be used as k_0=2, k_1=1, k_2=2.70, and k_3=0.4. Using this approximation, the required number of channels versus carried traffic for the specified GoS is shown in Fig. 5.

Finally, given a blocking probability objective, holding times and call arrival rates, a simple dimensioning rule for the number of APs can be obtained from Table 2.

5. SUMMARY

In this paper, we have introduced and discussed Multi AP concepts for SCO traffic in a Bluetooth based RIN. The considered Multi AP concepts offer simple processes to enable and control several voice calls in a service area simultaneously. Performance calculations using the Erlang model have shown that Multi AP scenarios using three or six APs instead of a single AP can significantly reduce the blocking probability. A simple dimensioning rule has been employed for the number of APs required to obtain a desired call blocking behavior. In future work, we will investigate options to exploit capacity remaining in the RIN for data services, i.e. asynchronous connectionless traffic. It also is envisaged to elaborate on inquiry performance for the different scenarios.

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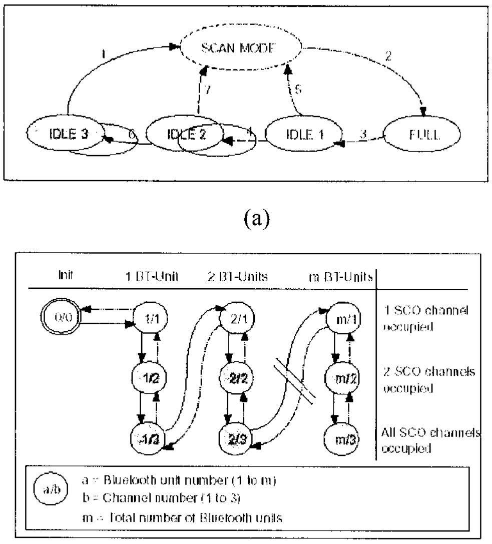
TABLE 1
BLOCKING PROBABILITY FOR DIFFERENT NUMBER OF CHANNELS AND OFFERED TRAFFIC

Arrival Intensity (calls/h)	Average Holding Time (min)	Offered Traffic (Erlang)	1 channel	1 AP = 3 channels	3 AP = 9 channels	6 AP = 18 channels
10	1	0.167	0.143	0.001	0.000	0.000
100	1	1.667	0.625	0.160	0.000	0.000
1000	1	16.667	0.943	0.831	0.510	0.130
10	3	0.5	0.333	0.013	0.000	0.000
100	3	5	0.833	0.530	0.037	0.000
1000	3	50	0.980	0.941	0.842	0.650

TABLE 2
MAXIMUM CALL ARRIVAL RATE

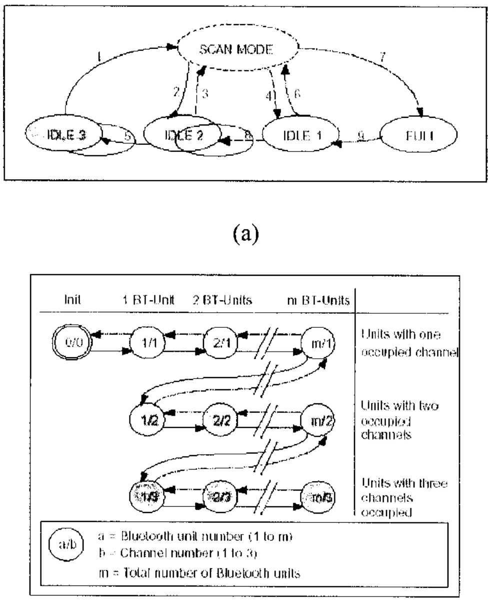
Nr. of Channels	Max. Allowed Blocking Probabilty	Average Holding Time (s)	Offered Traffic (Erlang) (from plot)	Arrival Intensity (calls/h)
3	0.01	100	0.456	16.42
6	0.01	100	1.909	68.72
9	0.01	100	3.784	136.22
12	0.01	100	5.879	211.64
15	0.01	100	8.110	291.96
18	0.01	100	10.442	375.91



(a)

(b)

Fig. 2. State diagram (a) and state reservation sequence (b) for SCO concept 1.



(a)

(b)

Fig. 3 State diagram (a) and state reservation sequence (b) for SCO concept 2.

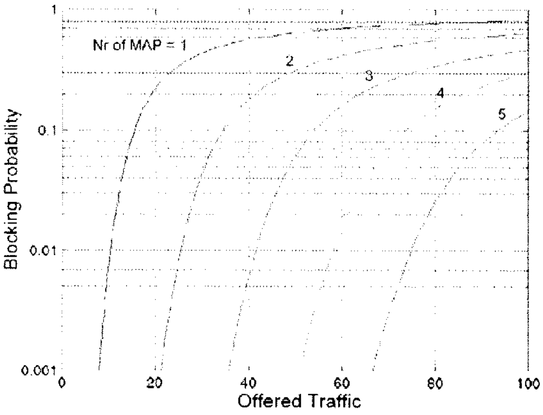


Fig. 4. Blocking probability according Erlang's first formula [6] versus offered traffic for different numbers of Multi APs (MAP).

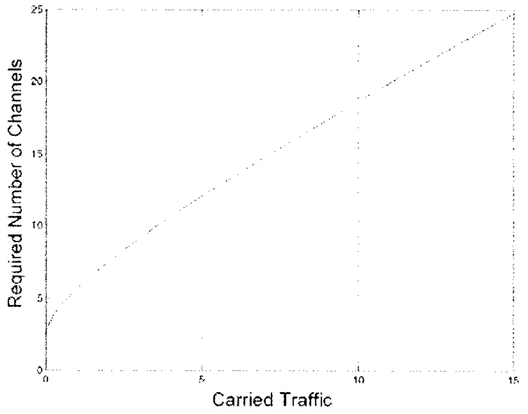


Fig. 5. Required number of channels as a function of carried traffic and a fixed blocking probability of 0.01.