Adaptive Load Balance and Handoff Management Strategy for Adaptive Antenna Array Wireless Networks

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Abstract: Wireless networks that employ adaptive antenna array (AAA) have been proposed to increase the traffic-carrying capacity and circuit quality. The AAA divided a cell into several areas. Variations in the traffic loads among areas will lessen the traffic-carrying capacity. Moreover, the handoff procedure usually takes place when the call crosses the area boundary. A larger number of areas will increase the system overhead for handling the handoff procedure. An ineffective management will increase the system overheads, such as code switch, data switch, and even network switch. The investigation proposes an effective load balance and handoff management strategy. These strategies are implemented to solve traffic-adaptation problem that can enhance the traffic-carrying capacity for variations in traffic. For the management of handoff procedure, our strategy considers the mobility of mobile hosts and the bandwidth utilization. It can decrease the number of handoff procedures and lessen the system overhead. Furthermore, the simulation results are presented to confirm the efficiency of the proposed strategy.

Key-Words: Adaptive antenna array, wireless network, load balance, traffic-adaptation, and handoff procedure.

1 Introduction

Technological advances and rapid development in handheld wireless terminals have facilitated the rapid growth of wireless communications. Since this tremendous growth of wireless communication requirements is expected under the constraint of limited bandwidth. The AAA frameworks that can provide more flexible to handle the limited bandwidth will be the mainstream for wireless networks [5, 15].

The geographical area of a system is covered by cells. In each cell, a base station using an AAA in the center supports the wireless communications. Each AAA has a number of sensors and each sensor has a number of the system codes used to establish communications sessions in a part area of this cell. Accordingly, the number of codes allocated to a sensor will affect the communication quality in this service area and the allocations of system codes among sensors will affect the traffic-carrying capacity of a system [2, 8, 11]. A reasonable allocation should provide more codes to a sensor with heavy traffic than a sensor with light traffic. Otherwise, it will experience that the heavy traffic sensors do not have sufficient codes to carry their traffic loads but the light traffic sensors have many available codes. Thus, the traffic-carrying capacity of a system is reduced and the call blocking probability arises. To consider real-life networks, the traffic distributions among sensors should be changeable according to various conditions. In order to achieve higher code utilization, when there are variations in traffic, the code allocations among sensors should be effectively reallocated according to current traffic profile [3-4, 13-14].

A cell is divided into several areas according to the service areas of sensors. Two neighboring sensors can not contain the same codes. Otherwise, the sensors that use the same codes to establish communication sessions will interfere with other. When a call arrives at a area, the codes of the targeted sensor can be used to handle the call. The problem in this assignment is on high-mobility mobile hosts (MH) that usually the area boundary. It will increase the number of handoff procedures. The handoff procedure usually takes place when the call crosses the cell boundary. In general, the handoff procedure including data transmission, code switching, and even network switching takes tens or hundreds ms. An effective decrease of the number of handoff procedures that can lessen the system overhead is meaningful [1-2, 6, 8-10, 12].

In light of above discussions, this study presents an adaptive load balance and handoff management strategy for AAA wireless networks. This strategy can dynamically allocate codes among sensors according to variations in traffic to solve the
traffic-adaptive problem and, accordingly, enhance the traffic-carrying capacity of cellular systems. For the handoff management, the assignment to calls considers the mobility of MHs to decrease the number of intra-handoff. The rest of this paper is organized as follows. Section 2 introduces the system model and the correlation research. In section 3, we describe the proposed strategy. The numerical results are given in Section 4. Conclusions are finally offered in Section 5.

2 Model & Correlation Research

Herein, first we introduce the system model. Then, use the definition of system model to describe the previous research contents.

2.1 System Model

The geographical area of a system is covered by cells. In each cell C_i, a base station using an adaptive antenna array (AAA) in the center supports the wireless communications. Each AAA has m sensors and each sensor can charge a region in C_i to provide communication service. For convenience, C_{i,1}, C_{i,2}, ..., C_{i,m} respectively represents the service areas of the m sensors in C_i.

The management of the system bandwidth is based on code division multiple access (CDMA) technique, where each cell can acquire all the system bandwidth B[7, 11]. Each sensor S_{ij} has a part B(S_{ij}) of system bandwidth B used to provide service of C_{ij}. A communication session (or a call) can be established if available codes can be allocated for supporting the communication between the mobile host and the sensor S_{ij}. Two sensors cannot concurrently assign the same code to calls if their geographical distance is less than the minimum reuse distance D_{min}; otherwise, their communication sessions will interfere with each other. This situation is referred to code interference [2, 12].

Definition 1: Given a sensor S_{ij} in cell C_i, the set of interfering neighbors of S_{ij}, denoted by IN(S_{ij}), is: IN(S_{ij}) = \{S_{ik} | S_{ik} \in C_i \text{ and } D(S_{ij}, S_{ik})<D_{min}\}, where D(S_{ij}, S_{ik}) is the geographical distance between C_{ij} and C_{ik}, denotes the interfering neighbors IN(S_{ij}) of a sensor S_{ij}.

When S_{ij} assigns a code to an incoming call, it must ensure that this code is not concurrently assigned to other calls in IN(S_{ij}). Code allocation to sensors must ensure if a code c is allocated to S_{ij}, no other sensors in IN(S_{ij}) can keep c as their code. Therefore, Definition 2 is the condition of code allocation.

Definition 2 (The condition of code allocation): Given two distinct sensors S_{ij} and S_{ik} in cell C_i, where S_{ik} \in IN(S_{ij}), the condition of code allocation between S_{ij} and S_{ik} is B(S_{ij}) \cap B(S_{ik}) = \emptyset.

For instance in Fig. 1, the area of cell C_i was divided to 12 subareas: C_{i,1}, C_{i,2}, ..., and C_{i,12} according to 12 sensors: S_{i1}, S_{i2}, ..., and S_{i12}. If D_{min} is 2 subareas away, IN(S_{ij}) = \{S_{i1}, S_{i2}, S_{i4}, S_{i5}\}. When S_{i3} was allocated to a B(S_{i3}), S_{i1}, S_{i2}, S_{i4}, and S_{i5}, their allocated codes that respectively are B(S_{i4}), B(S_{i3}), B(S_{i4}), and B(S_{i5}), can not have the same code with B(S_{i3}), i.e., any S_{ij} \in IN(S_{i3}), B(S_{i3}) \cap B(S_{ij}) = \emptyset. The traffic load \lambda(a) of an area a will determine its code allocation. The traffic load is defined as Definition 3.

Definition 3: The traffic load \lambda(a) of an area a is: \lambda(a) = t_a n_a, where t_a is the average call holding time in a and n_a is the average call arrival rate in a.

In a cellular system, the Erlang B formula, as shown in (1), can be used to evaluate the call blocking probability of an area C_{ij}, with the number n of available resources (codes) and the traffic load \lambda(C_{ij}) (in erlangs).

\[
EB(n, \lambda(C_{ij})) = \frac{\lambda^2(C_{ij})^{-1}}{n!} \sum_{k=0}^{n} \frac{\lambda(C_{ij})^{-1}}{k!}^{-1}
\]

(1)

The available bandwidth B is divided into two parts: B(S_i) and B = B(S_i). B(S_i) is termed as the cell-based resource and is used by high-mobility MHs. B = B(S_i) is termed as the subarea-based resource. The resource B = B(S_i) will be divided into several subsets and allocated to sensors, where the allocated resource of a sensor S_{ij} is denoted as B(S_{ij}). The allocated resource of each sensor is used by low-mobility MHs. The mobility is defined as Definition 4.

Definition 4: The Mobility of a MH mh is M(mh), where M(mh) is the average number of crossed areas (sensors) per unit time. When M(mh) is larger than a threshold \theta, the mh is termed as high mobility; otherwise, is termed as low mobility.

When a call arrives at an area, the targeted sensor S_{ij} will choose available codes from B(S_i) or B(S_{ij}). The available code c is defined as Definition 5.

Definition 5: A(B') = \{c | c \in B' and c don't assign to any mobile host\}.
2.2 Correlation Research

The Correlation Research divides into two parts: sensor-based code allocation and call-based code assignment. The sensor-based code allocation means the method to allocate each sensor $S_{ij}$ a part $B(S_{ij})$ of system resource $B$. Accordingly, when a call arrives at $C_{ij}$, the $S_{ij}$ assigns its allocated codes, using a call-based code assignment method, to assign codes for this call.

Given a cell $C_i$ with $m$ sensors $\{S_{i1}, S_{i2}, \ldots, S_{im}\}$ and the system bandwidth $B$. In general, each sensor $S_{ij}$ permanently keeps the same number of codes using to serve the incoming call of this area. This code allocation to sensors can be formally described as follows.

**Code Allocation:**

**Step 1.** Partition the sensors $\{S_{i1}, S_{i2}, ..., S_{im}\}$ in cell $C_i$ into $G_1, G_2, ...$ and $G_{cs}$ disjoint subsets, such that any two sensors in the same subset are apart by at least a distance of $D_{min}$. Accordingly, partition the available bandwidth $B$ into $B_1, B_2, ...$, and $B_{cs}$ disjoint subsets, where the $cs$ disjoint subsets are as fair as possible. ($cs$ is also termed as the cluster size).

**Step 2.** The subset $B_k$ is the allocated codes of sensors in $G_k$, where $k = 1, 2, ..., cs$.

For instance in Fig. 1, if the $D_{min}$ is 2 subareas away, i.e., $cs=3$, sensors $\{S_{i1}, S_{i2}, ..., S_{i12}\}$ can be divided into $G_1=\{S_{i1}, S_{i4}, S_{i7}, S_{i10}\}, G_2=\{S_{i2}, S_{i5}, S_{i8}, S_{i11}\}$, and $G_3=\{S_{i3}, S_{i6}, S_{i9}, S_{i12}\}$. Accordingly, the bandwidth $B$ can be divided into $B_1, B_2$, and $B_3$. Sensors in $G_k$ can acquire the codes $B_k$, where $k = 1, 2, 3$.

After the area $C_{i,j}$ acquired the resource $B(S_{ij})$, when a MH $mh$ requests $r$ capacity to establish communication session, the sensor $S_{ij}$ will find codes $c$ from $B(S_{ij})$ and the assignment procedure is presented as follows, where $|A(B(S_{ij}))|$ is the number of available codes in $B(S_{ij})$.

**Code Assignment:**

If $|A(B(S_{ij}))| \geq r$

Then assign code(s) $c$ to $mh$, where $c \subseteq A(B(S_{ij}))$ and $|c| = r$

Else block the request

### 3 Subject Strategy

The subject strategy is divided into two parts: the dynamic code allocation and the code assignment.

**Dynamic Code Allocation:**

For a cell $C_i$, the dynamic code allocation first partitions a part $B_0$ resource from the system bandwidth $B$. $B_0$ is used to serve the high-mobility MHs of the entire area of $C_i$. The other resource ($B - B_0$) then is partitioned into several subsets and allocates to the sensors. The allocation is described as follows.

**Step 1.** Partition the sensors $\{S_{i1}, S_{i2}, ..., S_{im}\}$ in cell $C_i$ into $G_1, G_2, ...$ and $G_{cs}$ disjoint subsets, such that any two sensors in the same subset are apart by at least a distance of $D_{min}$. Accordingly, partition the available bandwidth $(B - B_0)$ into $B_1, B_2, ...$, and $B_{cs}$ disjoint subsets.

**Step 2.** The subset $B_k$ is the allocated codes of sensors in $G_k$, where $k = 1, 2, ..., cs$.

The disjoint subsets $B_1, B_2, ...$, and $B_{cs}$ are determined according to the traffic loads of sensors in $G_1, G_2, ...$, and $G_{cs}$, respectively. For any $G_k$, where $k=1, 2, ..., cs$, the total traffic loads $\lambda(G_k)$ of sensors in $G_k$ is described as (2).

$$\lambda(G_k) = \sum_{C_{i,j}\in G_k} \lambda(C_{i,j})$$

(2)

For any $B_k$, where $k=1, 2, ..., cs$, if the sensors in $G_k$ acquired $B_k$ as their codes. The evaluated capacity, represented by the call blocking probability, is described as (3).

$$PB(G_k) = \frac{\sum_{C_{i,j}\in G_k} \lambda(C_{i,j}) \cdot \lambda(C_{i,j})}{\lambda(G_k)}$$

(3)

For all sensors in cell $C_i$, including $G_1, G_2, ...$, and $G_{cs}$ with $B_1, B_2, ...$, and $B_{cs}$, the evaluation is described as (4).

$$PB(C_i) = \frac{\sum_{n=1}^{cs} (PB(G_n) \cdot \lambda(G_n))}{\sum_{n=1}^{cs} \lambda(G_n)}$$

(4)
strategy is formalized as follows:

\[ \text{Step 1.} \text{ Partition the sensors } \{S_{i1}, S_{i2}, \ldots, S_{im}\} \text{ in cell } C_i \text{ into } G_1, G_2, \ldots, G_{cs} \text{ disjoint subsets, such that any two sensors in the same subset are apart by at least a distance of } D_{min}. \]

\[ \text{Step 2.} \text{ Choose an } C_i \text{ from all allocation forms } \{C_1, C_2, \ldots, C_{cs}\}, \text{ where } PB(C_{i}) \text{ is minimal among } \{PB(C_1), PB(C_2), \ldots, PB(C_{cs})\}. \]

\[ \text{Step 3.} \text{ According } C_i \text{ to allocated codes to sensors.} \]

For instance in Fig. 1 under \( D_{min} \) is the one subarea away, \( \{S_{i1}, S_{i2}, \ldots, S_{im}\} \) can be divided into \( G_1=\{S_{i1}, S_{i3}, S_{i5}, S_{i7}, S_{i9}, S_{i11}\} \) and \( G_2=\{S_{i2}, S_{i4}, S_{i6}, S_{i8}, S_{i10}, S_{i12}\} \). Suppose \( B - B_0 \) has 10 codes. Under the traffic distribution of Table 1, all allocation forms with the evaluations are presented as Table 2, where the allocation form that \( |A(B_1)|=7 \) and \( |A(B_2)|=3 \) presents best performance. Therefore, sensors \( S_{i1}, S_{i3}, S_{i5}, S_{i7}, S_{i9}, S_{i11} \) can respectively acquire 7 codes and sensors \( S_{i2}, S_{i4}, S_{i6}, S_{i8}, S_{i10}, S_{i12} \) can respectively acquire 3 codes.

**Dynamic Code Assignment:**

After each sensor \( S_{ij} \) acquired a number \( B(S_{ij}) \) of system codes, the dynamic code assignment strategy is used to assign codes to MHs for establish communication sessions. When a call requesting a number \( c \) of codes with the targeted MH \( mh \) arrives at the area of \( C_{ij} \), the system first check the mobility of \( mh \) and the available codes of \( B_{ij} \). If \( mh \) is a high mobility mobile host, i.e., \( M(mh)>th_{hi} \), the available codes of \( B_{ij} \) are sufficient, i.e., \( |A(B_{ij})|>c \), the system assigns available codes of \( B_{ij} \) to this call. Otherwise, the system checks the available codes \( B(S_{ij}) \) of sensor \( S_{ij} \). If the available codes of \( B(S_{ij}) \) are sufficient, i.e., \( |A(B(S_{ij}))|>c \), the system assigns available codes of \( B(S_{ij}) \) to this call. The formal representation is shown as Fig. 2.

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<th>Table 1: Traffic distribution</th>
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<th>Table 2: All allocation forms</th>
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4 Simulation Results
The simulation environment, as shown in Fig. 3, has 36 cells with 432 areas, arranged as 6-parallelogram structure, where the AAA divided each cell into 12 areas. The reuse distance is 2 subareas apart, where $cs$ is 3, respectively. The system has 64 codes, where each call requests a code. The total MHs are 10,000 and are divided into 70% high-mobility MHs and 30% low-mobility MHs. The average stay times of a high-mobility MH and a low-mobility MH respectively are 10 and 30. The 432 areas include 20% hot areas and 80% non-hot areas. When a MH moved from one area to the neighboring areas, if the neighboring area is a hot area, there are 70% to move to the hot area. The call arrival rate of each MH is generated according to the random process from 0.001 to 0.008 calls/hour and the average call holding time is 3 minutes. In the simulation, our allocation strategy is first employed to determine the codes to sensors. Accordingly, our code assignment strategy is then to assign codes to incoming calls.

Fig. 4 describes the call blocking probabilities of fixed strategy and our strategy with $|B_0|=0$ under overall calls, handoff calls, and new calls. The results reveal that our code allocation strategy can make the code assignment strategy more efficient to utilize the allocated codes. The reason can be described as follows. In fixed strategy, the code allocation cannot conform to the traffic distributions. Heavy sensors cannot acquire sufficient primary codes to serve the incoming calls when other light traffic sensors still have some available codes. Our strategy can adapt to the variations in traffic. Therefore, heavy traffic sensors have a larger probability to acquire more codes than light traffic sensors. Accordingly, the traffic-carrying capacity is larger.

Fig. 5 describes the call blocking probabilities of fixed strategy and our strategy with $|B_0|=3$. $|B_0|=3$ means 3 codes are reserved for high-mobility calls and if a call is assigned by this code, this call is unnecessary to perform handoff procedures in the same cell. The results reveal that our strategy including the code allocation strategy and the code assignment strategy is efficient to larger the system capacity. Fig. 6 (a) describes the average number of handoffs of a call under $|B_0|=0$, 3, and 6. Fig. 6 (b) describes the handoff decrease rates of $|B_0|=3$ and 6 based on $|B_0|=0$, the results reveal that under $|B_0|=3$ (=6), the handoff decrease rates are 6.54%~23.59% (10.71%~27.94%). Handoff procedures will increase the system overheads, such as code switch and data switch. Therefore, our strategy can decrease the system overheads.

5 Conclusions
The investigation proposed an effective load balance and handoff management strategy. These strategies are implemented to solve traffic-adaption problem that can enhance the traffic-carrying capacity for variations in traffic. For the management of handoff procedure, our strategy considers the mobility of mobile hosts and the bandwidth utilization in sensors. It can decrease the number of handoffs and lessen the system overhead. Considering ergonomic and economic factors to reallocate codes among cells that can satisfy new trends in the telecommunication industry is one of our future works.
Fig. 4: Call blocking Probability with $|B_0|=0$.

Fig. 5: Call blocking Probability with $|B_0|=3$. 
Fig. 6: Handoff rate

References: