Vertical Handoff Provisioning and Capacity Planning in the Deployment of Hybrid Networks

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Abstract— **The demand for hybrid networking, in which different access technologies are integrated to support mobile networking, has witnessed significant increase recently. One major challenge in hybrid networking is vertical handoff provisioning. In this paper a mobility-based network planning optimization for hybrid networks is proposed. The optimization objective is to minimize the rate of up-going vertical handoff events and to maximize the total number of users supported by the network. The optimal placement of APs with respect to these two objectives is formulated as an integer programming problem. Our results show that considering the mobility pattern in the planning phase of network deployment can significantly improve the infrastructure performance.**

I. Introduction

Hybrid networking or next generation wireless networking is expected to be the future of wireless networking, where different access technologies such as IEEE 802.11/16 and third generation (3G) cellular networks are integrated to support ubiquitous wireless networking [1]. This networking architecture consists of two layers. At the top layer, the overlay network works as a more global service and in the bottom layer, the underlay network is considered as a more local service. Overlay network availability is in general higher compared to the underlay network but it provides lower data-rates at higher expenses [2]. Examples of this type of integration are IEEE 802.11/16 or IEEE 802.11 with third generation cellular networks. An example of hybrid network deployment is shown in Fig. 1.

The optimal deployment of wireless infrastructure has been extensively studied in the literature [3], [4], [5]. The conventional constraints in the planning of wireless networks are capacity, signal strength and frequency channels. In [3] the problem of finding a simple WLAN network planning method, to maximize both the coverage area and the overall signal quality, is explored. The authors in [4] present a series of Internet Transit Access Point (ITAP) placement algorithms to build efficient multi-hop wireless neighborhood networks. The goal is to find the optimal deployment of ITAPs that minimizes the total number of required ITAPs under certain user bandwidth requirement constraints and various wireless link models. In [5], the optimal placement of wireless relays is derived, through numerical solutions to integer programming. However, in this paper, we are concerned with the optimal planning of hybrid networks.

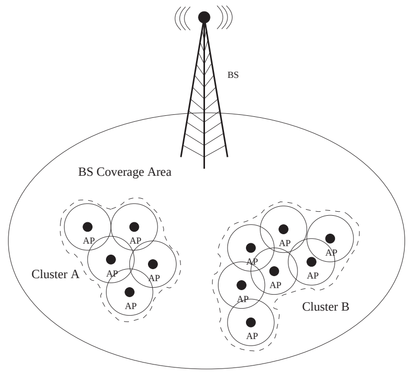

Fig. 1. Sample hybrid network structure; APs deployment has resulted in having two independent clusters.

Another issue in wireless mobile networking is handoff and mobility management. Since the radio spectrum is limited, pico/micro-cellular and WLAN architectures will be used more and more in the future to provide users with high data-rates. The result is that as the radius of coverage area is decreasing the crossing of coverage borders, commonly referred to as handoff, which was not initially a problem has become one of the major networking performance criteria. Handoff between two different access technologies is called vertical handoff (VHO) [6]. Vertical handoff from a lower layer to an upper layer is an undesirable incident, because resources at higher levels are more limited [6]. In this paper we show that in access technologies such as IEEE 802.11, because of their shorter range, handoff occurrences can be a major issue which occurs very frequently and must be considered in the network planning phase. In addition, we show that the conventional capacity-based planning methods are not as useful as we may expect, mainly because the average utilization of WLAN APs are generally far below saturation point. In other words, in WLANs the capacity insufficiency event is much more infrequent compared to handoff events.

Therefore, one objective in the planning of the network can be the minimization of the vertical handoff rate. Intuitively, in some network deployments it might be better if we bundle some APs together instead of spreading them over the deployment area. That way although the APs might not be supporting the highest possible amount of traffic, the reduction in the vertical handoff rate can be significant. However, this single objective to minimize the rate of vertical handoff events is not enough since in the worst case the algorithm may choose the areas with the least amount of demand because the handoff rate would be small for those areas. Here, we take a second objective to be the total amount of supported traffic which we wish to maximize.

To the best of our knowledge, this paper is the first work where the inefficiency of conventional planning methods due to the more frequent handoff events is considered and an integer programming method to minimize the vertical handoff rate is proposed. In what follows, we first present our system model and assumptions and then the integer programming formulation. Finally the performance results and conclusion are presented.

II. Assumptions and System Model

In the network planning or upgrade process the goal is to add N new APs to the the underlay architecture which may already have N_0 APs. The deployment area is divided into an H-by-W grid space and each block is called a cell. We assume that each cell may contain an AP. The set of adjacent cells with an AP inside them form a cluster. When the planning is done we might have several independent clusters as depicted in Fig. 1. Vertical handoff occurs when a mobile user having an active call leaves a cluster and starts to use the overlay networking services. In this paper our objective in the network planning is to minimize the total rate of the up-going vertical handoff events and to maximize the total supported number of network users.

One key observation here is that the user mobility pattern is independent of the infrastructure presence and its variations. Generally this is true, because users are commonly not concerned about how the networking services are achieved and they make their movements decisions independent of that. This allows us to look at the steady-state occupancy distribution of each cell independently of how the final deployment for the underlay network is done. Furthermore, we assume that all arrival and departure processes are memoryless. As shown in Fig. 2, we denote by $\lambda(i,j)$ the call arrival rate to cell (i,j), the call termination rate by $\mu(i,j)$ and call handoff rates from cell (i,j) to each of its neighboring cells by $H(i,j,k)$.

III. Mobility and Equilibrium state

We divide the vertical handoff minimization problem into two parts. Here, we use the mobility pattern to find the expected number of users in each possible AP coverage area and in the next section we use this knowledge to formulate the problem as an integer program. Clearly, the handoff rate out of each cell is proportional to the number of users in the cell. To find the expected number of users in each cell $n(i,j)$, we develop a queuing model by considering every cell as an **M/M/**∞ queue. Here, it is assumed that the capacity of each cell is unlimited which is not unrealistic knowing that in practice the utilization of underlay APs are normally far below saturation.

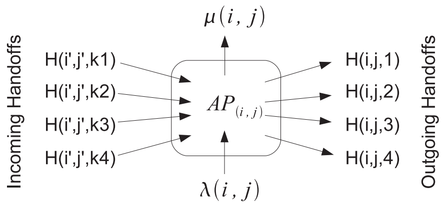

Fig. 2. Traffic arrival and departure from AP(i,j).

In the **M/M/**∞ queuing model each call goes to the server as soon as it arrives and no queue is formed and the total waiting time is equal to the system service time. The service time for each call can be computed by considering that a call leaves a cell when it either terminates or handovers to another cell. Let us denote the service time for a call in cell (i,j) by $S_t(i,j)$ we can write that

$$S_t(i,j) = \min(T_{t(i,j)}, T_{h(i,j,1)}, T_{h(i,j,2)}, T_{h(i,j,3)}, T_{h(i,j,4)})) \quad (1)$$

where $T_{t(i,j)}$ denotes the call duration in cell (i,j) before its final termination and $T_{h(i,j,k)}$ represents the time to handoff to k^{th} neighbor in the grid. Assuming that all the processes are memoryless, the random variable $S_t(i,j)$ is exponentially distributed with parameter $\mu(i,j)+\sum_{k=1}^{4} H(i,j,k)$. Note that in a grid each cell is adjacent to 4 other cells. In fig. 3 a cell and its neighborhood and our numbering convention are shown.

Little's theorem can be used to compute $n(i,j)$ given the total arrival rate to cell (i,j) and the average service time as

$$n(i,j) = \lambda_{total(i,j)} \times [\mu(i,j) + \sum_{k=1}^{4} H(i,j,k)]^{-1}, \quad (2)$$

where, the total arrival rate to cell (i,j), $\lambda_{total(i,j)}$, is the sum of the call arrivals(new call generation) $\lambda(i,j)$ and handoff arrivals from adjacent cells. From the traffic equations we have

$$\lambda_{total(i,j)} = \lambda(i,j) + \sum_{(i',j') \epsilon S_{neighbors}(i,j)} H(i',j',k')n(i',j'), \quad (3)$$

where $S_{neighbors}(i,j)$ is the set of cells adjacent to cell (i,j) and k' is chosen such that cell (i',j') is attached to cell (i,j) by its $k'th$ side. Equation (2) can be used to eliminate $\lambda_{total(i,j)}$ as

$$n(i,j) \times \left\{ \mu(i,j) + \sum_{k=1}^{4} H(i,j,k) \right\} - \sum_{(i',j') \epsilon NGH(i,j)} H(i',j',k')n(i',j') = \lambda(i,j). \quad (4)$$

This forms a set of $H \times W$ independent linear equations which can be solved to find $n(i,j)$.

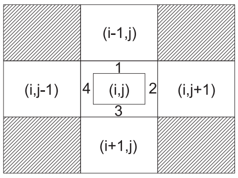

Fig. 3. Cell(i,j), its neighbors and our numbering convention.

IV. Optimization Problem Formulation

In this section we present the steps to formulate the optimization problem as an integer programming problem. For each cell (i,j), we have a variable $x(i,j)$ that indicates whether there is an AP in the cell:

$$x(i,j) = \begin{cases} 1 & (i,j) \text{ has an AP} \\ 0 & (i,j) \text{ does not have an AP.} \end{cases} \tag{5}$$

Then, the total number of users supported by a certain AP deployment can be written as

$$n_{total} = \sum_{i=1}^{H} \sum_{j=1}^{W} n(i,j)x(i,j). \tag{6}$$

To formulate the up-going vertical handoff rate, $V(i,j,k)$, from cell (i,j) through its kth side, we introduce a variable $\hat{x}(i,j,k) = x(i',j')$, where cell (i',j') is located on cell (i,j)'s kth side. It is easy to verify that $x(i,j)\left[1-\hat{x}(i,j,k)\right] = 1$ if and only if $x(i,j) = 1$ and $\hat{x}(i,j,k) = 0$, which means (i,j) is a cell on the border of a cluster and handoffs calls going outward through the kth side are vertical up-going handoffs. Then we can use $x(i,j)\left[1-\hat{x}(i,j,k)\right] = 1$ as an indicator of vertical handoffs. For each cell we have

$$V(i,j,k) = n(i,j)H(i,j,k)x(i,j)\left[1-\hat{x}(i,j,k)\right]. \tag{7}$$

Furthermore, the total up-going vertical handoff rate of a system is

$$V_{total} = \sum_{i}^{H} \sum_{j}^{W} \sum_{k=1}^{4} V(i,j,k). \tag{8}$$

Our goal is to find the optimal AP placement which minimizes V_{total} and maximizes N_{total} at the same time. However, the two objectives do not necessarily have the same optimal location set. We adopt the approach used in [7] and consider the following objective function:

$$\begin{aligned} F_0 &= V_{total} - \psi n_{total} \\ &= \sum_{i=1}^{H} \sum_{j=1}^{W} n(i,j) \left[\sum_{k=1}^{4} H(i,j,k) - \psi\right] x(i,j) \\ &\quad - \sum_{i=1}^{H} \sum_{j=1}^{W} \sum_{k=1}^{4} n(i,j)H(i,j,k)x(i,j)\hat{x}(i,j,k) \end{aligned} \tag{9}$$

Here, $\psi \in [0,+\infty)$ is the weighting factor. Then the optimization problem is formulated as

$$\begin{array}{ll} \text{minimize} & F_0 \\ \text{subject to} & \sum_{i=1}^{H} \sum_{j=1}^{W} x_0(i,j)x(i,j) = N_0 \\ & \sum_{i=1}^{H} \sum_{j=1}^{W} x(i,j) = N_0 + N \end{array} \tag{10}$$

where $x_0(i,j)$ indicates the existing infrastructure, i.e., if cell (i,j) already has an AP in it, $x_0(i,j) = 1$; otherwise $x_0(i,j) = 0$. The first constraint maintains that for every $x_0(i,j) = 1$, the new deployment must satisfy $x(i,j) = 1$, in order to keep the existing APs in the system. The second constraint formulates the constraint that the new system should have N new APs and $N_0 + N$ APs in total.

Notice that F_0 is a quadratic function. In order to have a linear objective function, we replace the quadratic terms in F_0 with a new variable $y(i,j,k)$:

$$\begin{aligned} F &= \sum_{i=1}^{H} \sum_{j=1}^{W} \sum_{k=1}^{4} n(i,j)\left[H(i,j,k) - \psi\right] x(i,j) \\ &\quad - \sum_{i=1}^{H} \sum_{j=1}^{W} \sum_{k=1}^{4} n(i,j)H(i,j,k)y(i,j,k) \end{aligned} \tag{11}$$

and the optimization problem can be reformulated as

$$\begin{array}{ll} \text{minimize} & F \\ \text{subject to} & \sum_{i=1}^{H} \sum_{j=1}^{W} x_0(i,j)x(i,j) = N_0 \\ & \sum_{i=1}^{H} \sum_{j=1}^{W} x(i,j) = N_0 + N \\ & y(i,j,k) \le x(i,j) \\ & y(i,j,k) \le \hat{x}(i,j,k) \\ & y(i,j,k) \ge x(i,j) + \hat{x}(i,j,k) - 1 \end{array} \tag{12}$$

It is easy to see that the above constraints $y(i,j,k) = x(i,j)\hat{x}(i,j,k)$, since $x(i,j)$, $\hat{x}(i,j,k) \in \{0,1\}$.

Note that there is no coverage continuity constraint in the above optimization problem formulation. However, as it will be shown in the next section, when suitable ψ is used, continuity is achieved automatically.

V. Simulation Results

In this section, we study the performance of our algorithm for different preexisting infrastructure installations and different choices of parameters.

A. Simulation Setup

We generate a 10-by-10 grid as shown in Fig. 4. A street is modelled as a vertical path with a relatively high arrival rate passing through in the middle of the region. There is a hot spot on each side of the “street”, representing buildings with a large number of users in them. After solving a set of 10×10 independent linear equations as described in Section II, we find the average number of users $n(i,j)$, shown as grey scale in Fig. 4.

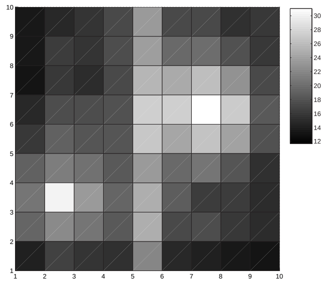

Fig. 4. Average number of users.

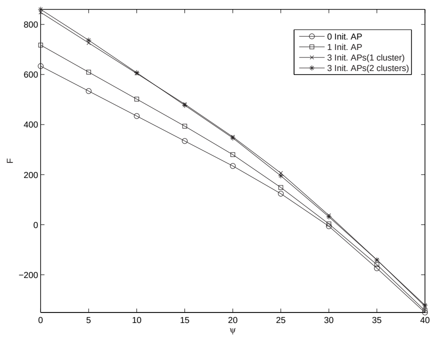

Fig. 5. Minimum F for different initial settings.

B. Effect of Initial Deployment

We run our simulation for four initial AP settings: 1) no AP is installed in the region; 2) only one AP is installed at the "hottest" spot on the right half of the region; 3) three APs are installed as a cluster around the "hottest" spot; and 4) two APs are installed around the "hottest" spot and one AP is installed in the hot spot on the left half of the region. The goal is to upgrade the deployment so that the total number of APs would be 15.

Fig. 5 shows the optimal value of F achieved for the four initial settings with ψ varying over a wide range. It can be seen that the optimal F in all cases is lower bounded by the optimal F achieved with no preexisting AP. This is true becuase the feasible set in the case of no initial AP is the largest and hence $F_{No\ initial\ AP} \leq F$. Comparing the results for case 2 with cases 3 and 4 shows that the optimum value when there is only one cluster is always better than the case where there are two clusters. This is because unless the new APs connect the two clusters together, the total boundary is always larger than the case when there is only one cluster, and a larger boundary will results in more vertical handoffs.

C. The Effect of Parameters selection

The value of ψ in the objective function $F_0 = V_{total} - \psi n_{total}$ determines the desired balance between provisioning of handoff events and accommodating more users. When ψ is large, n_{total} is more important and the optimization process

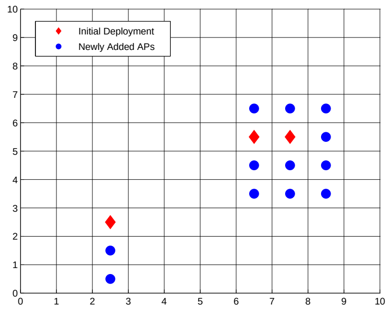

Fig. 6. Upgraded AP deployment.

will end up choosing cells with larger $n(i,j)$'s. When ψ is close to 0, we are more concerned about V_{total} and this results in choosing cells on the border of the deployment area. Figure 6 shows the optimization result for the experiment case where we have two clusters at the start and we want to add 12 new APs to the system for $\psi = 40$. As shown in this figure, the optimal solution places two clusters of APs around the two hot spots.

VI. Conclusion

In this paper we have proposed a mobility-based network planning algorithm for hybrid networks. The problem of optimal AP placement is formulated as an integer programming problem. The optimization objective is to minimize the rate of up-going vertical handoff events and to maximize the total number of users supported by the network. Our performance results indicate that the optimization algorithm makes efficient decisions regarding AP placement. Also, the proposed algorithm can be used to provide design guidelines on evolutionary upgrading of future hybrid networks.

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