Beamforming Mesh Deployment

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***Abstract*—Beamforming**

I. Problem Formulation

The objective of the mesh network deployment is to minimize the number of deployed mesh nodes with the constraint of full coverage of the target area and connectivity to the Internet. In this section we first describe the the motivation, then we introduce the depolyment constraints, which the QoS requirements of the vendors and clients. Further, we formulate the deployment problem as a graph-theoretic model with the QoS constraints.

A. Motivation

Wireless propagation is the behavior of the signal loss characteristics when wireless signals are transmitted through the wireless medium. The strength of the received signal depends on both the line-of-sight path (or lack thereof) and multiple other paths that result from reflection, diffraction, and scattering from obstacles [1]. The widely-used Friis equation characterizes the received signal power P_r in terms of transmit power P_t, transmitter gain G_t, receiver gain G_r, wavelength λ of the carrier frequency, distance R from transmitter to receiver, and path loss exponent n according to [2]:

$$P_r = P_t + G_t + G_r + 10n \log_{10} \left(\frac{\lambda}{4\pi R} \right) \tag{1}$$

Here, n varies according to the aforementioned environmental factors with the value of two to five in typical outdoor settings [3]. Through the propagation model, in the same environment with a constant pathloss exponent n, lower frequency white space bands offer not only more bandwidth, but also large communication range, which could potentialy be used to reduce the number of access points.

Beamforming is a technique signals received at each antenna element are intelligently combined to improve the performance of the wireless system [4]. As shown in Fig. 1, with the same transmit power, beamforming technology could propagate the energy in directional lobe with a larger communication range. Other than increasing communication range, beamforming could also potentially be used to suppress interfering signals, combat signal fading, and increase the capacity of wireless systems [5]. However, applying beamforming technology, an access point could not reponse the request out of the beam lobes, which increase the transmission time. The performance of throughput will be lower.

Combine both beamforming and white space bands could expand a single mesh node coverage region and adapt the natural non-uniform traffic demand distribution The decrease of access points number means huge budget saving in a wireless network deployment.

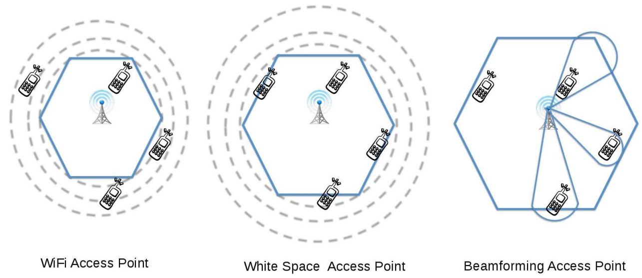

Fig. 1. Communication Range of Access Points

Typically, the deployment of wireless access networks is subject to coverage and capacity constraints for a target area. Coverage is defined with respect to the ability of clients to connect to access points within their service area. We use a coverage constraint ratio of 95% in this work for a target area [6]. Capacity is defined with respect to the ability of a network to serve the traffic demand of clients. Spatial reuse allows improved capacity, but increases the cost of deploying a network by increasing the total number of access points required. Hence, for densely populated areas the greatest level of spatial reuse possible is often desired which could be offered through an expensive new access point working in other frequency or low cost beamforming with smart scheduling. In contrast, sparsely-populated rural areas have lower traffic demand per unit area. Thus, aggregating this demand with lower-frequency, white space bands and further propagated beamforming lobes could be highly effective in reducing the total number of access points required to achieve similar coverage and capacity constraints. Moreover, since less TV channels tend to be occupied in sparsely populated areas [7], a larger number of white space bands can be leveraged in these areas.

B. Model and Problem Formulation

As opposed to previous works such as [6], [8], [9], we focuse on hetergenous beamforming access point selection for wireless access networks which jointly employ white space and beamforming technology. Through beamforming and white space agility, an access point performance could be improve by the coverage area and throughput. Also with a smart beamforming scheduling, fairness in a network could be achieved through QoS time distribution.

We assume the service vendor has a limited number of spectrum resources and wireless radios have similar configuration, such as transmit power, gains and beam lobes. Each radio on an access point operates with a classic protocol model [10]. Then we can further analyze the performance of access point under different traffic demand distribution according to the capacity and coverage constraint.

A network deployment should ideally provide network capacity equal to the demand of the service area to maintain the capacity constraint. The demand of a service area could be calculated as the summation of individual demands all over the service area $D_a = \sum_{p \in P} D_p$. Since household demand for Internet has been previously characterized [11], D_a could represent the population distribution f and service area k as $D_a = \sum_{f \in F, k \in K} \bar{D_p} * f * k$. The capacity constraint could be represented with access points set M according to:

$$\sum_{m \in M} C_r^m \geq \sum_{f \in F, k \in K} \bar{D_p} * f * k \tag{2}$$

At the same time, the wireless network must additionally satisfy the coverage constraint in the service area where the access points provide connectivity for client devices. Generally, a coverage of 95% is acceptable for wireless access networks [6]. The object of this work is to find the best possible number of access points so that the network has good connectivity and enough capacity to satisfy the traffic demands.

Under the capacity and coverage constraints, the serveice area of an access point is limited by the propagation range, beamforming lobes and scheduling methods. The radius of service area r_s could be represented as:

$$r_s = min\{r_p, r_c\} \tag{3}$$

r_p represents the propagation range of the access point, r_c is the capacity range of a radio in the access point. A simple example is when the traffic demand is distributed uniform in a circle, from Eq. 2 the capacity range r_c could be noted as $r_c = \sqrt{k/\pi}$. Under beamforming situation, the capacity range r_c will vary according to the beam lobe scheduling. Moreover, the propagation range and capacity rang could be determined by the environment, traffic distribution and power control [6]. These parameters could be pre-detected from existing measurements, census and public or private database. When a target area is given, we could model the traffic demand, access points and potential connectivity links as a graph according to the parameters from database.

Thus, the target area with pre-defined parameters could be modeled as a connectivity graph with vertexes represented as the centrilized traffic demand of a certain area and potential access points locations. The edges note the links between the locations. Oppose to previous works, [**?**], [6], [8], [12] we formulate the input connectivity graph as a 3 dimension graph $G = (V, E, F)$, where centralized traffic demand, access points location candidates and links with or without beamforming form a unified connectivity graph.

The vertexes in the modeled input graph represent a set C of separated target area with traffic demands. The set C consists of physical coordinates represetnting target areas where client coverage is desired, analogous to the area to be covered in a geometric formulation and the traffic amount need to be served. And also the set of potential access points M is a second part of the vertexes in the modeled graph. The potential locations of access points are assumed known through the infrastructure conditions. The vertex set of the input connectivity graph is the union of potential access points and centralized traffic demand locations as $V = C \cup M$.

The output of the problem is expected to be an graph $G' = (V', E', F')$ which marks the access points and chosen links with/without beamforming. The connectvity and capacity constraints

The nodes in the graph assume traffic demands of the target area could be discreted into a set C. The set C consists of physical coordinates representing where coverage is desired, analogous to the area to be covered in a geometric formulation.

Previous work focus on the non-uniform coverage regions generated by environment. then find the solution to deploy minimum number of access points. In this work, we use frequency agility and beamforming to generate non-uniform coverage regions to reduce the number of access points for a network deployment.

To do that...

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