Capacity-constrained Design of Resilient Multi-tier Wireless Mesh Networks

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In this work we investigate the issue of automated design of Wireless Mesh Networks (WMN). The general scenario we envision is that of constructing WMNs with WLAN networks as clients (tier 1) and a mesh network (tier 2) to provide inter-WLAN as well as gateway connectivity. Our main aim in this work is to a) design capacity-constrained WMNs, b) build resilient WMNs with transient demands.

We initially investigated the issue of capacity-constrained design of single-hop wireless networks. Adhoc deployment of such networks cannot adequately address QoS-constrained capacity requirements [4]. We developed a tool, the Wireless Infrastructure Deployment tool (WIND) , that generates appropriate topologies for single-hop wireless networks under given constraints [3]. The tool considers the nodes to be deployed and their associated characteristics (number of links, capacity constraints etc.), an abstract graph of the deployment area and QoS constraints to generate appropriate logical topologies.

WIND starts with the set of network elements to be deployed (Node Units (NU)) and proceeds to then recursively construct the topology using various heuristics. At each stage of the recursion, WIND successively generates a sub-graph (Composite Unit (CU)) of the topology by deriving it out of the sub-graphs generated at the previous stage and hence finally resulting in the network topology(figure 2). Such an hierarchical topology construction approach allows us to tightly control demand satisfaction.

Now, removing wired connectivity to APs is also an important goal in order to increase the cost savings accrued by avoiding the deployment of a wired backhaul connectivity. But additionally, a suitable technology is necessary to replace the large bandwidth capability of wired networks. WMNs have emerged as an enabling technology to alleviate this issue of providing cost-efficient backbone connectivity to the AP [1].

While the design of WMNs falls in the same class of network design problems as encountered in wired as well as cellular networks, there is a significant difference in the node capabilities and the associated constraints and cost-functions. For example, the wireless nature of the links (including backbone links between mesh nodes) give rise to cost-functions not encountered in other networks, and also the use of multi-hop wireless transmission results in additional scheduling constraints.

The design of such a multi-tier network also has to consider the time-varying demands of the clients or the addition of new client nodes. In order to do so the design methodology has to build resilient networks to withstand these transient demands. We look at the WMN design problem as a special case of the traditional network design problem for optimal node location and topology construction [2]. With WiMAX as the enabling WMN technology and WLAN as the underlying first-tier network to be connected, we investigate various urban and rural deployment scenarios (figure 1). Our aim is to compare and classify the different scenarios vis-a-vis their cost of deployment.

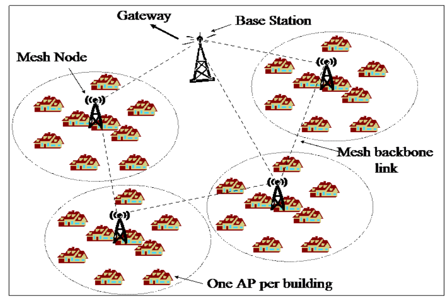

Fig. 1. A typical mesh network scenario.

The following scenario presents the problem in an urban setting. We consider an area where the mesh network is going to be deployed. Each building in the area has an AP which provides the connectivity between the clients inside the building and the mesh backbone. It does this by associating itself with the nearest mesh node (based on some cost function). The mesh nodes can have multiple directional antennas (links) in order to communicate with both the APs as well as other mesh nodes.

An AP therefore has at least two radio links, one providing internal connectivity and one providing the connection to the mesh backbone. The internal link is assumed to be an 802.11 device while the external link maybe a mesh (i.e. WiMAX) link. Note that we are mainly concerned with the demand generated at each AP, hence the type of the internal link or the underlying sub-network topology is *irrelevant* to the problem as long as there is no overlap in the frequency allocated to the links (in order to avoid interference). Also note that the demands at the AP (which is the root node of the underlying sub-network) is generated as one of the outputs of the WIND topology construction process.

Now the problem for this scenario is defined as follows. Given the demands at each AP and a set of potential mesh

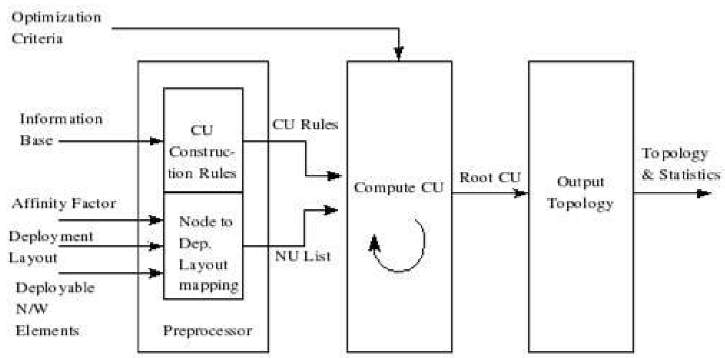

Fig. 2. WIND framework.

node locations, the problem is to find the optimal number of mesh node locations (from the given set) as well as the mesh topology to satisfy the demand constraints. Some of the constraints placed on the problem are :

- Link capacity constraint: Demand volume flowing on each potential link (of each node) should not exceed the capacity of the link.
- Demand satisfaction: Each AP demand in the network should be satisfied.
- Link bounds: There is an user-defined upper bound on the number of mesh links.

We have formulated the WMN design as an mixed-integer linear programming problem. We then used the CPLEX solver to generate topologies with varying parameters (the number of demands, demand volumes, number of links etc.). The problem as expected scales exponentially with even a small increase in node numbers due to the increase in search space required by the formulation. But the initial results for small problem sizes (6 APs, 5 potential mesh nodes) are encouraging. They provide us an insight to the issues faced in such design problems.

For example, an important aim was to observe the effect of cost functions on the resilience of the topology to changes in demands. The use of a cost function based on transmission power proves to be a better estimate than one based on distance. Not only does this reduce the transmission power required, by forcing nodes to establish links with nearer nodes, it also reduces the volatility. Initial results show that the computed topology changes infrequently with change in demands and hence showing resilience. We are currently working on improving the cost functions to correctly represent this phenomenon.

Also, we are looking into developing heuristics to reduce the MILP search space in order to compute topologies for real life network scenarios and validating the capacity constraints using simulations. We also plan to integrate the second-tier wireless mesh backbone design process with the WIND tool [3]. This will allow us to completely automate the design of a wireless mesh network.

References

[1] Ian Akyildiz, Xudong Wang, and Weilin Wang. Wireless mesh networks: a survey. *Computer Networks*, 2005.

[2] Michal Pioro and Deepankar Medhi. Routing, flow, and capacity design in communication and computer networks. 2004.

[3] Raghuraman Rangarajan and Sridhar Iyer. Automatic topology generation for a class of wireless networks. *IEEE International Conference On Personal Wireless Communications*, 2005.

[4] Raghuraman Rangarajan, Sridhar Iyer, and Atanu Guchhait. Automated design of VoIP-enabled 802.11g WLANs. *OPNETWORK*, 2005.