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Design of Heterogeneous Wireless Mesh Network for LTE

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GJCST-E Classification: C.2.1, C.1.3

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Design of Heterogeneous Wireless Mesh Network for LTE

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I. Introduction

Present cellular networks, including LTE, suffer from the increase in the number of user devices connected to the network in a region. The network-wide performance of LTE can be improved by setting up more Base Stations for planned frequency reuse and by gaining more spectrum to accommodate a greater number of users. The cost of expanding the infrastructure by setting up more Base Stations in crowded regions and the high spectrum licensing costs make this approach unattractive to service providers. Further, methods such as cell-splitting require extensive field-study to determine the appropriate location for new BSs. Base Stations in large open areas with relatively low number of users should cover more of the region, compared to BSs in areas of high demand. In practice, there is no alternative long-term solution for situations such as temporary changes in demand due to crowded events and network coverage problems at cell edges, although a recent trend to offload some of the LTE data to Wi- Fi has shown positive results.

IEEE 802.11 or Wi-Fi network access technology is a popular and mature alternative for accessing the Internet without the spectrum licensing costs as it operates in the ISM band or Industrial, Scientific and Medical bands released for local networking. But, the limited range of Wi-Fi APs or Access Points restricts the usage of the technology to local and personal area networking and networking up to a few kilometers using directional antennas. The support for mobility is limited to those devices that can be classified as nomadic rather than true mobile devices, unlike cellular technologies.

Wireless Mesh Networks using IEEE 802.11 offer a mesh topology to access Internet services and thus support expansion of the network similar to ad-hoc networks without centralized infrastructure. Mesh networking technologies also provide greater fault tolerance and network reliability as multiple paths can exist from a source to a destination. However, the wireless link quality in such networks is not guaranteed due to interference among densely located Wi-Fi mesh nodes. This and the multihop nature of mesh networks will mean a lower network capacity. Packet-loss and resource consumption in multihop networks is comparatively very high due to the very nature of the network. Further, since mobile wireless nodes can create links dynamically in the mesh network, nodes can get isolated and form island nodes which cannot communicate with the rest of the network. The conversion of a node in a multihop path into an island node may not be immediately registered by the other nodes in the path since ad-hoc routing and management protocols are not optimized for mesh networks.

Next generation networks must integrate the basic features offered by these networks, while addressing the limitations of the individual networks, for improved service quality and data rate without buying more spectrum or investing in large centralized infrastructure. Such a solution is preferred due to the wide adoption of LTE cellular technology and since it supports the coexistence of the different wireless technologies and wired networks. The combined network uses the existing centralized infrastructure and can be updated following changes in demand with incremental additions to the network as and when needed. The expansion of the network does not require setting up more centralized infrastructure. Such a network which combines Wi-Fi mesh network and LTE can utilize the diversity or heterogeneity of the different

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technologies to overcome the limitations of each of the access technology when employed independently. The mesh part of the network can be expanded in proportion to increase in demand thus improving scalability of the combined network, and the multihop nodes of Wi-Fi mesh can relay packets from/to conventional mobile nodes which are at the edge of the LTE cell, thereby essentially improving coverage of the LTE network. Further, fault-tolerance of the heterogeneous network is improved considerably since redundancy is introduced by the mesh topology and by the use of multiple network access technologies which can eliminate the creation of island nodes. A heterogeneous network utilizing LTE and switch) between the transmission technologies is developed in the form of a heterogeneous routing protocol. The routing protocol is composed of two parts: a system to populate and maintain the routing tables of the heterogeneous devices which the architecture employs, and a heterogeneous routing algorithm for utilizing the routing tables. The performance of the proposed architecture which incorporates the routing

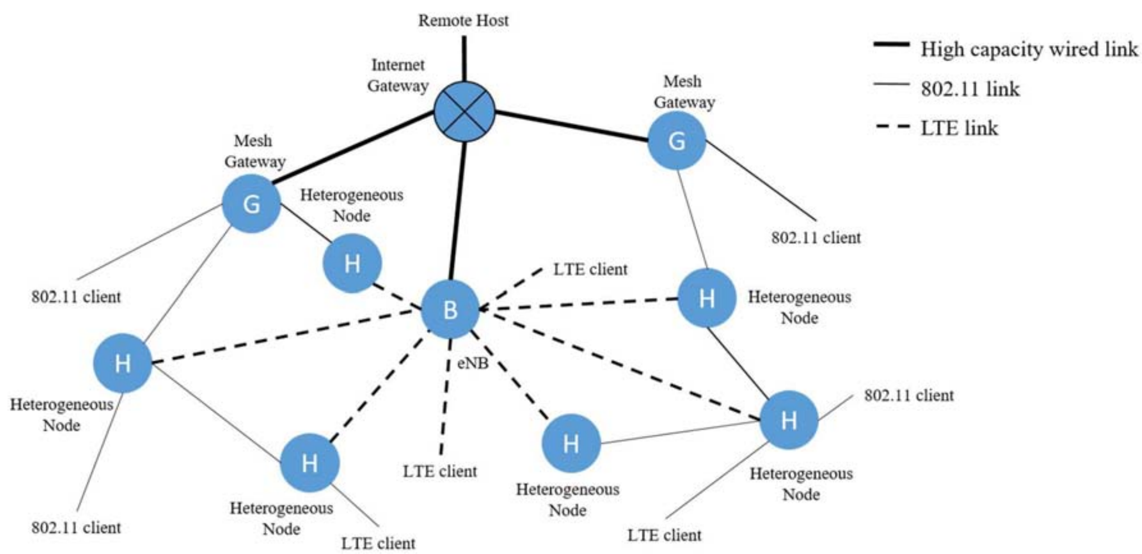

Fig. 1: Heterogeneous wireless network

Wi-Fi mesh can distribute load across the network technologies by offloading some of the LTE packets to the Wi-Fi network to improve performance and handle congestion in LTE network.

The level of integration should be such that the combined network act as one single network for obtaining maximum performance. Interoperability of the different technologies must be considered since many devices use different network access technologies, underlying protocols and operating systems. The heterogeneous network architecture should be capable of avoiding long multihop paths in the mesh network and island nodes to reduce packet loss and resource consumption for a better QoS. Other challenges to achieving this include unavailability of a mechanism for heterogeneous routing i.e., switching between the two transmission technologies, considering the heterogeneity in protocols used by the two technologies. Further, heterogeneous routing requires that the routing or switching protocol operate with close association to the MAC layer since packets from LTE have to be offloaded to Wi-Fi network and vice-versa based on network parameters of each access technology. Thus, the heterogeneous routing protocol should invariably be a cross layer routing protocol.

A new heterogeneous wireless mesh network architecture which introduces tight integration between the two network access technologies IEEE 802.11s wireless mesh and LTE is proposed. Further, an accompanying mechanism to route (or protocol is evaluated using the open-source discrete-event network simulator NS3 (Network Simulator 3) for its community support, flexibility and support for LTE networks, IEEE 802.11s mesh and creation of heterogeneous nodes.

II. Existing System

The definition of 'WiFi offloading' has been shaped by the growth of LTE technology to mean WiFi offload or handover between LTE network and WiFi network. For mobile phone users, it can mean access to wider bandwidth probably at a lower cost or for free. For mobile network operators, it would help reduce the load on the LTE network by offloading the subscriber to WiFi network. The service providers may not be able to charge for WiFi network usage as for LTE network but they may be able to get some gain from load balancing and still keep some portions of the money from the mobile user by directing to switch to the WiFi network serviced by the mobile network operator. Thus, with respect to end-user experience, several models for WiFi offloading currently exist. In UEinitiated Wi-Fi offloading, the user equipment is initially connected to the LTE network while there is no WiFi network available. The user switches to the WiFi network when the UE is within range of the WiFi network based on certain criteria. Thus the handover between the networks is initiated from the user side. Similar to UE-initiated offloading, in network initiated WiFi offloading, the user equipment is initially connected to the LTE network while there is no WiFi network available. The user switches to the WiFi network when the UE is within range of the WiFi network based on certain criteria. Here, the handover between the networks is initiated by the network. The Wi-Fi network is coupled to the LTE network in two ways. one is through a Trusted Access Point and the other one is through Non-Trusted Access Point. In Trusted Access, the WiFi Security is protected by the 3GPP network, Thus, the end user does not need any separate authentication process between 3GPP and non-3GPP Network. For Non- Trusted Access, WiFi Security is not protected by the 3GPP network, the user has to go through separate authentication process between 3GPP and non-3GPP Network, the non- 3GPP network here being the WiFi network.

The main difference between the existing system for WiFi Off loading and offloading in the heterogeneous network is that setting up the heterogeneous network architecture requires changes to be made only in the region covered by a single eNodeB and not to the remaining parts of the network.

III. Network Architecture

The heterogeneous network architecture is built with the LTE Base Station (eNodeB) at its center to extend and improve the features of the LTE network in the region covered by the Base Station. That is, the architecture covers a single cell of the LTE network and each cell uses the same architecture to improve capacity. Close proximity of the LTE and Wi-Fi transmitters cannot cause interference as the two network technologies use different frequency bands. Mesh Gateway nodes in the Wireless Mesh Network (WMN) connect it to the Internet Gateway. The Internet Gateway is connected by high-capacity wired path to the Evolved Packet Core (EPC) of the LTE network and also connects the eNodeB. Thus, the Internet Gateway acts as the server to provide Internet access to the heterogeneous network. Many nodes which support multiple transmission technologies called Heterogeneous Nodes (HetNodes) are positioned across the area of the LTE cell and form the backbone of the WMN. This means that the HetNodes support multiple network interfaces and thus each HetNode can communicate with its neighboring HetNode using either LTE transmission technology or Wi-Fi links. Conventional clients such as mobile phones or laptops can connect to the Mesh Gateways or the HetNodes and/or the LTE Base Station, or by using wired interfaces of the Mesh Gateways or HetNodes.

In the downlink (DL) scenario, i.e., while a packet meant to reach a client node connected to the heterogeneous network from the Internet travels to the network, the Internet Gateway is responsible to route the packet to either LTE or Wi-Fi network through one of its interfaces. Thus, the architecture does not support switching back to LTE after the Internet Gateway routes the packets to the Wi-Fi network. In the uplink (UL) case, multiple interfaces of the HetNodes can be utilized.

Each of the interfaces in a heterogeneous node will have a different network address or IP address. There should be a mechanism to list the addresses of each node in the network with the Internet Gateway. The Internet Gateway should also be aware of the associations between nodes in different levels of the multi-level architecture primarily because it is responsible for switching between transmission technologies in the downlink. Thus, each type of node maintains routing table(s) which are forwarded to the Internet Gateway using control messages, and the routing tables are also utilized by the heterogeneous routing algorithm to route packets between the different transmission technologies. The routing protocol also specifies the access technology to be used for communicating control messages to update the routing table of the Internet Gateway.

Each HetNode should maintain routing table for routes to every other heterogeneous node in the Wi-Fi mesh network. This is achieved using OLSR (Optimized Link State Routing) ad-hoc routing protocol. HetNodes should also maintain a list of available Mesh Gateways and a default Mesh Gateway. The OLSR protocol is extended using hop count to a Mesh Gateway and number of nodes connected to it (load) as metrics to select the default Mesh Gateway. The Mesh Gateway with the shortest hop count is selected by each HetNode. The load metric is used to select one out of multiple Mesh Gateways which might have the same hop count. The clients and the heterogeneous nodes send control messages to the Internet Gateway by including both the IP address of the LTE and Wi-Fi interfaces via LTE access technology.

Mesh Gateways maintain a routing table that lists the addresses of the HetNodes associated with it and sends update messages to the Internet Gateway when there are changes in the routing table. The routing tables in Mesh Gateways are updated using request messages from the HetNodes that try to connect to the Mesh Gateway. Each Mesh Gateway has an entry in the routing table of Internet gateway that lists all the heterogeneous nodes associated with the mesh Gateways. Further, client nodes need not support new routing tables.

The heterogeneous routing algorithm in a HetNode and the Internet Gateway, should select the

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transmission technology based on the parameters from all the network access technologies a node utilizes, and also consider the entries in the heterogeneous routing table. Routing in the WMN is left to the ad-hoc routing protocol (OLSR) which also maintains the routing tables used for routing within the mesh network.

IV. Routing Algorithm

The proposed Heterogeneous Wireless Mesh Network Routing algorithm is based on reinforcement learning and uses the Q-learning reinforcement learning algorithm as the algorithm does not require a model of the environment and is thus suited to wireless networks. Reinforcement learning algorithms evaluate past events and decisions to converge at an optimal state. Q-learning algorithm calculates reward of each action based on feedback to converge to the optimum. CHR selects the network access technology by using parameters from Wi-Fi and LTE networks and learns from previous decisions if the selected transmission technology improve performance of the heterogeneous network. The algorithm selects the transmission technology with higher Qvalue. In the uplink, CHR is used by the HetNodes to switch between LTE or Wi-Fi, and is used only by the Internet Gateway in the downlink. The original Q-learning algorithm re-computes the Q-value during a cycle to be used for decision making in the next cycle and is given as:

$$Q(t_i) = (1-\alpha)Q(t_{i-1}) + \alpha\big(R(t_i) + \gamma Q(t_{i+1}) - Q(t_{i\ 1})\big) \quad (1)$$

where, α is the learning rate ($0 \leqslant \alpha \leqslant 1; 0$ implies no learning), γ is defined as the discount value (=0 implies reinforcement learning is opportunistic i.e., maximizes only the immediate short-term reward) and R is the reward. Ti represents the current time or cycle and t_{i-1} represents the previous time or cycle.

CHR algorithm adopts RARE (Rate Adaptation based on Reinforcement Learning) rate control protocol operating in the MAC layer of wireless mesh networks. RARE updates the transmission rate of a node in the WMN in relation to the collision and interference in the neighboring nodes, using reinforcement learning. Thus, the transmission rate of a Wi-Fi device controlled by RARE can be used as a metric to assess the quality of the links in the WMN and the probability of successful packet transfer. The other metric used by CHR is the probability to access the channel in WMN. The Wi-Fi channel quality for node d is given as:

$$CQW^d(t_i) = RW^d(t_i)/RW_{max} \quad (2)$$

where, RW is the transmission rate of the IEEE802.11 device.

The network parameters used by CHR to assess LTE link quality are the probability of successful transmission and the load. The load is obtained from the Radio Link Control (RLC) protocol layer in eNodeB and the HetNodes, and corresponds to the buffer length of each LTE interface and HetNodes. LTE uses separate buffers for uplink and downlink and thus the respective buffers are accessed by CHR during downlink and uplink. The LTE load on the HetNode can be obtained as:

$$LL^d(t_i) = BufL^d(t_i)/BufL_{max} \quad (3)$$

where, BufLd is the number of packets in the LTE transmission buffer for node d and BufLmax is the maximum capacity of the buffer in terms of number of packets. Larger values of LLd (0≤LLd≤1) points to congestion at the node.

The Q-learning algorithm is adapted for WMNs using the access network parameters as:

$$QW^d(t_i) = (1-\alpha)QW^d(t_{i-1}) + \alpha\Big(SRW^d(t_{i-1}-t_i) + CQW^d(t_i) - QW^d(t_{i-1})\Big) \quad (4)$$

where,

$$SRW^d(t_{i-1}-t_i) = STW^d(t_{i-1} - t_i)/TTW^d(t_{i-1}-t_i) \quad (5)$$

Here, QW represents the probability of accessing the Wi- Fi channel, SRW is the success rate of node d since the last update of the transmission rate, STW is the number of successful transmissions and is obtained from the MAC layer of IEEE802.11 Wi-Fi device on HetNode by counting number of acknowledgements (ACK) received for each transmission. TTW denotes the total number of transmissions of the Wi-Fi device during the period.

The Q-learning algorithm adapted for LTE gives the probability of switching packets to LTE:

$$QL^d(t_i) = (1-\alpha)QL^d(t_{i-1}) + \alpha\Big(\big(SRL^d(t_{i-1}-t_i) + \big(1-LL^d(t_i)\big)\big) - QL^d(t_{i\ 1})\Big) \quad (6)$$

where, SRL is the success rate in LTE device since the last update of the probability to access LTE network and is given as:

$$SRL^d(t_{i-1}-t_i) = STL^d(t_{i-1}-t_i)/TTL^d(t_{i-1} - t_i) \quad (7)$$

where, STL is obtained from the RLC layer using ACK and is the number of successful transmission for a node during the period using LTE network. TTL is the total number of transmissions using LTE during the period.

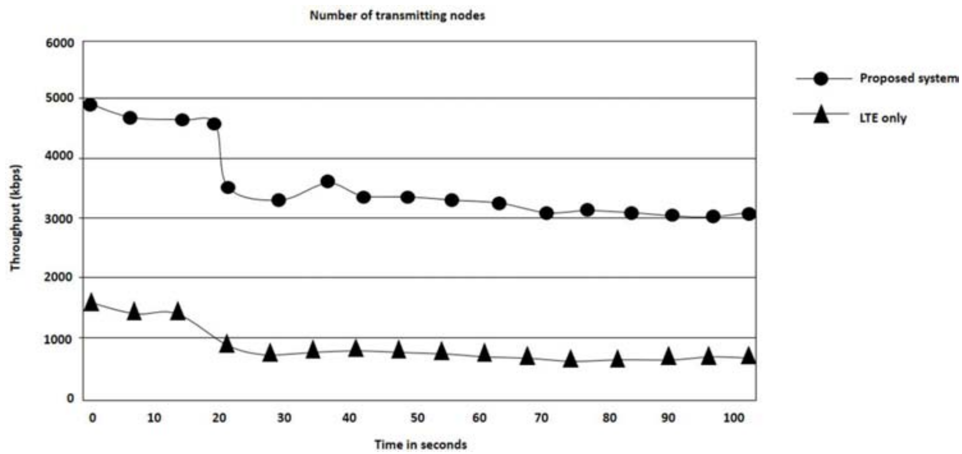

Figure 2: Throughput comparison of Proposed system with LTE-only network when 50 nodes are transmitting simultaneously

The Heterogeneous Wireless Mesh Network Routing algorithm can be divided into two stages namely exploration stage, during which the parameters are initialized, and the learning stage which keeps constant track of the parameters and evaluates previous actions to converge to the optimum and base the decision on the optimum value. During the exploration stage, a limited number of packets are transmitted through LTE and IEEE802.11s interfaces which works as a training sequence to the reinforcement learning algorithm. The influence of duration of the exploration stage on the system throughput is minimal as the algorithm converges during the cycle. The Q-learning algorithm calculates the probability of successful data transmissions of each network access technology during the learning stage and updates the Q-values. CHR then selects the interface with the higher Qvalue between the two to transmit the packets.

V. Conclusion

The heterogeneous network architecture, which integrates LTE and IEEE 802.11s, is a better solution to offload LTE traffic to unlicensed spectral bands in high density metropolitan areas. The combined virtual network makes use of heterogeneity in the network from utilizing two different network access technologies with different topologies, spectral bands etc. to improve the performance of each of the individual networks. The architecture uses LTE to prevent occurrence of island nodes in the wireless mesh network in which measures have also been taken to eliminate long multihop paths. The benefits of the underlying centralized infrastructure are utilized while providing better scalability to the network removing bottlenecks in wireless mesh networks by limiting hop count. A heterogeneous routing protocol is introduced for the purpose of the heterogeneous wireless mesh network architecture. The routing protocol performs routing table maintenance and heterogeneous routing by using parameters from the constituent networks using distributed intelligence through the use of the Q-learning algorithm. Routing within the wireless mesh network is left to the ad-hoc routing protocol. The combined network improves LTE network capacity by 2 to 3 times compared to that of the underlying individual network and also addresses issues of cell-edge network coverage among others and reduces cost of expansion of the network.

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