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A Unified Access Model for Interconnecting Heterogeneous Wireless Networks

by Saleil Bhat, Venkateswara R Dasari, and Vinod K Mishra

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14. ABSTRACT <p>Battlefield communication networks consist of various heterogeneous networking technologies. Heterogeneity can create problems of interoperability and challenges in creating a unified network. Two of the challenges in making heterogeneous networks interoperate seamlessly are the existence of disparate Media Access Control (MAC) layers and control plane protocols.</p> <p>A network model that can abstract disparate MAC layers in heterogeneous networks and interconnect them using a unified and centralized connection broker could potentially solve the problems preventing seamless connectivity in heterogeneous networks. The controller can accept signals from a variety of access technologies and convert them to the appropriate form before forwarding. Using C++, we modeled the behavior of a unified access controller for heterogeneous wireless networks in the <i>ns-3</i> environment. We allowed 2 simulated wireless networks with 2 different access technologies to communicate with one another via a virtual network device acting as the controller. The conversion process was performed using the <i>ns-3</i> emulated net device model, which can change an <i>ns-3</i> simulation signal of any particular access technology into a virtual packet and vice versa. Our simulated model validated the unified access control design for heterogeneous networks. It can be used as a framework for further testing and also as the foundation for a new physical design over which the heterogeneous networks operate seamlessly.</p>					
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Student Bio

Saleil Bhat is a third-year undergraduate at Columbia University. He is majoring in Electrical Engineering and plans to graduate in May 2016. Saleil attended the Army High Performance Computing Research Center Summer Institute for Undergraduates in 2013. There, he worked under Dr Hector Garcia-Molina on a project entitled Categorical Analyses of Web Traffic Data, which was concerned with organizing and graphing internet traffic data for discovering trends. In the future, he hopes to continue exploring new paradigms for networking.

1. Introduction/Background

There are many ways in which a heterogeneous network (HN) can be defined. In the present work, an HN will be defined as the network in which devices with different access technologies are interconnected.¹ This situation is very common with battlefield communications in which Soldiers carry devices based on different access technologies, and communication between them is necessary for the mission success. However, an HN is not as robust as a homogeneous network because the control plane of HN is inherently fragmented; each access technology has its own control function. This is the source of several problems:

- Incompatibilities between control protocols could lead to network failure.
- There is no robust failure notification system. If a device of one access technology goes down, another access technology's control plane may not be notified or updated.

Furthermore, these problems are exacerbated in military applications. Unlike consumer technologies, for which there are ample data on how different access technologies interact, military communication protocols are nonstandard, which means compatibility issues may still have yet to be discovered.

In the present work, a network access control model is proposed, which is independent of a Media Access Control (MAC) layer specific to an access technology. This approach solves many of the wireless network access problems encountered in an HN. The key element of the proposed model is a centralized Software-Defined Networking Controller, which is in charge of all data flow controls. This controller can accept connection requests from various access technologies and act as a gateway for each access technology subnet. Figure 1 presents a topology in which the controller has access to a complete map of the network, allowing it to avoid the issues listed above.

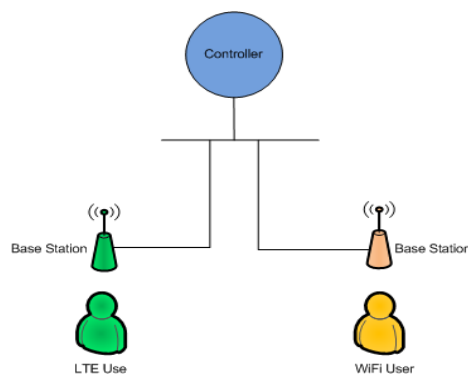


Fig. 1 Unified access control model for heterogeneous wireless networks

In this project, the *ns-3* network simulator was used to create a unified access model for an HN. We simulated networks with 2 different access technologies, WiFi and long-term evolution (LTE), and created a communication pathway between them via a central controller node. Our simulation serves as a validation of the proposed network design for unified network access, and it lays the foundation for implementing a Software-Defined Networking (SDN)-mediated unified access model.

2. Experiment

Our method was to create a virtual network between simulated WiFi and LTE subnets. The desired end result was a system consisting of 3 virtual machines (VMs) in which 2 VMs simulated the 2 wireless subnets while the third VM acted as the controller.

The packet-send procedure in this system proceeds as follows:

- 1) A simulated LTE user device sends a packet with a WiFi user device as its destination.
- 2) The packet is transmitted to the LTE access point, which converts it into a “virtual” packet.
- 3) This virtual packet is sent via the virtual network to the controller VM, where the controller node receives then forwards it to the third VM.
- 4) The WiFi access point receives this virtual signal, converts the virtual packet into a simulated packet, and sends it to its final destination, the user device.

This procedure is illustrated in Fig. 2.

We used *ns-3* to emulate the network access device to allow our simulated nodes to interact with the virtual network. An *ns-3* emulated network device can accept a simulated *ns-3* signal and convert it into a “real” signal and vice versa.² To implement the above procedure, each access technology’s access point and the controller node must have an emulated network device installed on them.

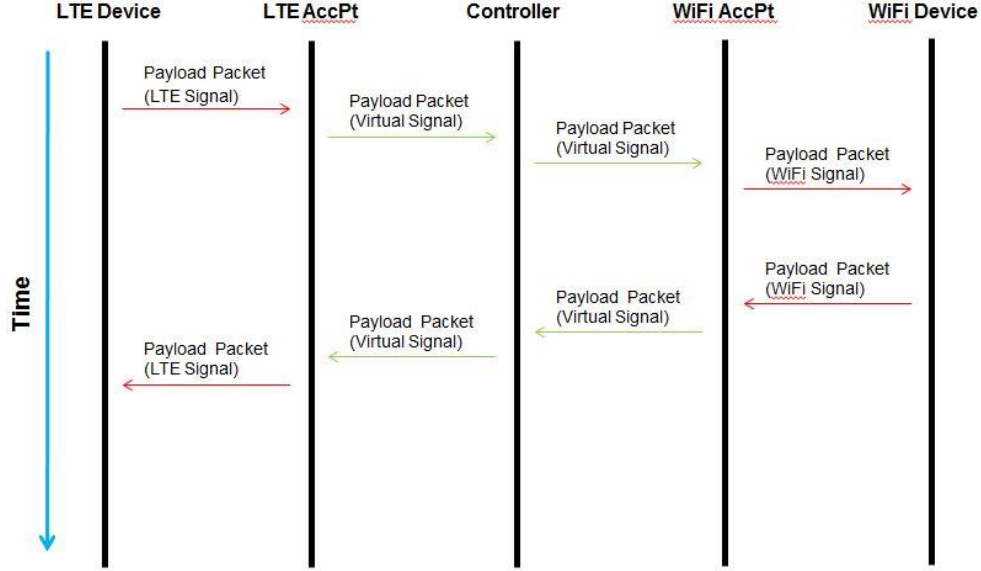


Fig. 2 Data flows in unified wireless network access model

Realizing this goal also required creating and configuring a virtual network between the VMs. Each simulated node has its own MAC address, which is independent of the MAC address of the VM on which it is running. When an *ns-3* node attempts to send a packet to another node on a different VM, it refers to the simulated MAC address and not to that of the VM.³ Therefore, each VM in the network must be put in a “promiscuous” mode. Otherwise, the VMs will just drop the received virtual packets, since they are addressed to a MAC address other than their own. This model was built via a 3-stage process:

- 1) First, we created a proof-of-concept simulation using a nonwireless access technology as one of the subnets.
- 2) Second, we created a simulation using the 2 wireless access technologies, WiFi and LTE, but using 2 VMs instead of 3.
- 3) Finally, we expanded the 2 VM WiFi/LTE simulations into a 3-VM system, thus achieving our desired goal.

2.1 Proof-of-Concept with WiFi and Carrier-Sense Multiple Access (CSMA)

We first developed a proof-of-concept simulation demonstrating that 2 different access technologies can be configured to communicate with each other via a central controller. The 2 access technologies used were 802.11 (WiFi) and a Carrier-Sense Multiple Access (CSMA) protocol similar to Ethernet. Our simulation used 2 VMs. The first VM ran an *ns-3* application that simulated both

end points of the network: the CSMA subnet and the WiFi subnet. Each subnet consisted of 2 nodes: a user device and an access point. The second VM ran an *ns-3* application with a blank node; it did not have any particular simulated access technology. This node functioned as our controller. We found that this model functioned as planned: a communication pathway between the 2 subnets via the controller node was established.

2.2 Two Virtual Machine Configurations with WiFi and LTE

We replaced the CSMA subnet in the previously mentioned simulation with an LTE subnet and attempted to establish a connection by the same mechanism. However, this attempt was unsuccessful. Modifications to the *ns-3* source code were required to achieve the same results as the WiFi/CSMA simulation. We discovered that the original attempt failed because the order in which the IP address is assigned to a node influences how that node behaves in *ns-3*. In our simulation, each access point had 2 IP addresses assigned: one for the access technology subnet to which it belongs and another for the network between the access point and the controller node (the emulated network).

If the access technology subnet IP address is assigned *before* the emulated network IP address, then the node behaves as if it only has one IP address: that of the access technology subnet. On the other hand, if the subnet IP address is assigned *after* the emulated network IP address, then the node can be referenced by either address.

In the original implementation of LTE in *ns-3*, the packet gateway (PGW) node, which serves as the Internet access point for LTE networks, is not created by the user directly. Rather, it is instantiated automatically by the helper class used when one creates an LTE user device. Part of this process is the assigning of IP addresses. Thus, when one creates an LTE network in *ns-3*, its access point is assigned an IP address before one has the chance to give it another. Because of this, the access point cannot also behave as a member of the emulated network.

We modified the *ns-3* source code such that the PGW is not assigned an IP address automatically. We also added a method to the helper class allowing the user to set the PGW LTE network IP address. In our simulation code, we assigned the emulated network IP address to the PGW node first and then called the method to set its LTE network IP address. Using these steps, we succeeded in obtaining the same results as the WiFi/CSMA simulation.

2.3 Three Virtual Machine Configurations with WiFi and LTE

We expanded the above simulation to work with 3 VMs instead of 2. To do this, we removed the simulated nodes of one access technology from the simulation code. We then moved them to an *ns-3* application running on the third VM. Thus, our configuration now involved 3 different VMs, each running an *ns-3* application. Two VMs ran wireless subnet simulations, while the third ran a blank node that served as the medium through which the wireless subnets could communicate with each other.

3. Results and Discussion

Using the 3-VM LTE/WiFi configuration, we placed a User Datagram Protocol (UDP) client application on the LTE user device and a UDP echo server application on the WiFi user device. We modified the UDP client and UDP server source code to provide text-based feedback to verify that 2-way communication is occurring. We also ran Wireshark on the controller node VM to monitor the packet traffic seen by the controller. Since every packet must pass through the controller before reaching its destination in our topology, this allowed us to monitor the entirety of the network traffic during our simulation. The results are shown in Figs. 3–5.

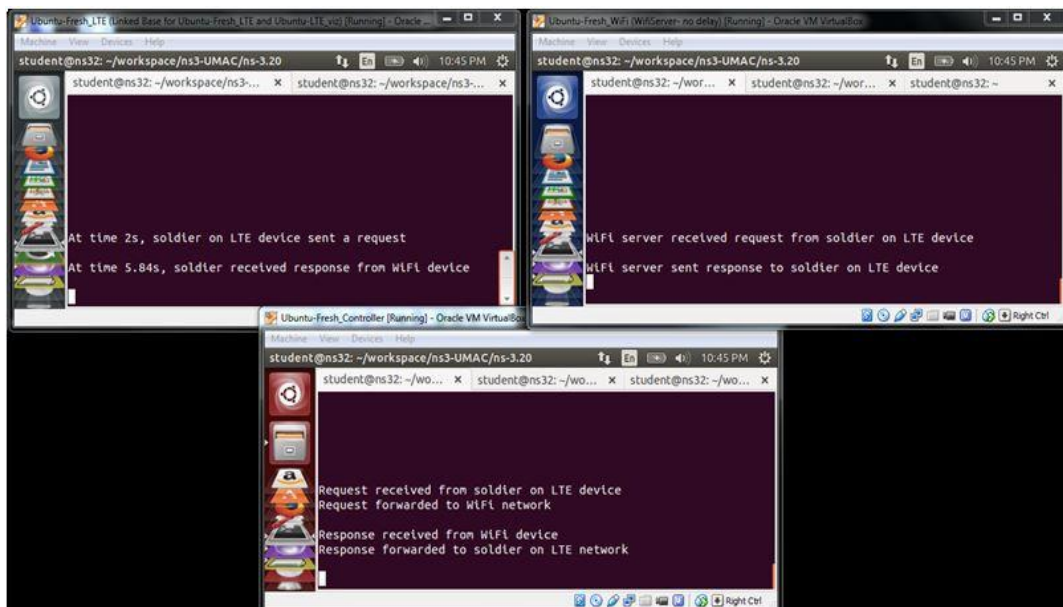


Fig. 3 Text feedback from unified access simulation

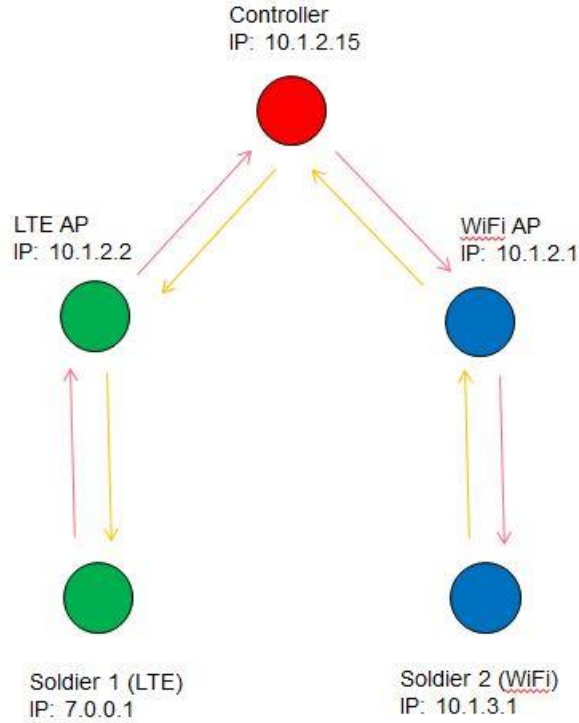


Fig. 4 Unified simulation network topology

Source	Destination	Protocol	Size	Info
00:00:00_00:00:03	Broadcast	ARP	60	Who has 10.1.2.15? Tell 10.1.2.2
00:00:00_00:00:01	00:00:00_00:00:03	ARP	42	10.1.2.15 is at 00:00:00:00:00:01 Source port: 49153 Destination port: cisco-sctp
7.0.0.1	10.1.3.1	UDP	1066	
00:00:00_00:00:01	Broadcast	ARP	42	Who has 10.1.2.1? Tell 10.1.2.15
00:00:00_00:00:02	00:00:00_00:00:01	ARP	60	10.1.2.1 is at 00:00:00:00:00:02 Source port: 49153 Destination port: cisco-sctp
7.0.0.1	10.1.3.1	UDP	1066	
00:00:00_00:00:02	Broadcast	ARP	60	Who has 10.1.2.15? Tell 10.1.2.1
00:00:00_00:00:01	00:00:00_00:00:02	ARP	42	10.1.2.15 is at 00:00:00:00:00:01 Source port: cisco-sctp Destination port: 49153
10.1.3.1	7.0.0.1	UDP	1066	
00:00:00_00:00:01	Broadcast	ARP	42	Who has 10.1.2.2? Tell 10.1.2.15
00:00:00_00:00:03	00:00:00_00:00:01	ARP	60	10.1.2.2 is at 00:00:00:00:00:03 Source port: cisco-sctp Destination port: 49153
10.1.3.1	7.0.0.1	UDP	1066	
7.0.0.1	10.1.3.1	UDP	1066	Source port: cisco-sctp Destination port: cisco-sctp
7.0.0.1	10.1.3.1	UDP	1066	Source port: 49153 Destination port: cisco-sctp
7.0.0.1	10.1.3.1	UDP	1066	Source port: cisco-sctp Destination port: 49153
10.1.3.1	7.0.0.1	UDP	1066	Source port: cisco-sctp Destination port: 49153
10.1.3.1	7.0.0.1	UDP	1066	Source port: cisco-sctp Destination port: 49153

Fig. 5 Packet trace on controller node in unified network simulation

Figure 3 shows the text feedback, which verifies that both the LTE client’s initial request and the WiFi server’s subsequent response are able to reach their respective destinations via the controller node. Figure 4 shows the network topology with the IP addresses of every node labeled (the subnet IP addresses of access points are not shown). Figure 5 shows the output of Wireshark monitoring the controller node VM. This further confirms that the controller is functioning as desired: when it receives a packet addressed to one of the end user devices, it forwards the packet to the appropriate access point.

4. Summary and Conclusions

We have created and validated a unified network access model for heterogeneous wireless networks by abstracting the MAC layer using a controller. Communication between subnets of different access technologies can be achieved via a centralized controller. The framework we created could be used as the basis for larger-scale simulations or for testing real-world applications. Most importantly, our simulation serves as a template for implementing a unified MAC layer network using SDN.

SDN is a network program with a programmable, centralized control plane.⁴ SDN protocols can be used to mediate access between nodes of an HN. The method, developed for creating a unified MAC layer, can be extended to work with the SDN framework. In our simulation, signals could be passed between the subnet access points and the controller by refactoring them as virtual packets. Similarly, in a heterogeneous SDN network, access points send and receive messages from the SDN controller by sending SDN protocol packets.

We plan to modify our model to work with OpenFlow, an open-source SDN implementation.⁵ Our desired goal is to drive our simulated topology with a real OpenFlow controller instead of the blank node we are currently using. Doing so will require significant modifications to the *ns-3* OpenFlow model. The current implementation of OpenFlow aggregates the switch (the access point in our topology) and the controller onto the same node, which is not an accurate representation of how OpenFlow actually functions. For our next step, we will attempt to remove the internal controller from the *ns-3* OpenFlow controller and instead create the pathway for the *ns-3* OpenFlow switch to communicate with an external device. Success in this endeavor will be a significant step toward creating a real-world implementation of a unified MAC layer HN.

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