A Femtocell-based Testbed for Evaluating Future Cellular Networks

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Abstract

This paper argues that the network community needs research testbeds for cellular wireless networks, and introduces a femtocell-based testbed, dubbed Cell-Lab, which is currently being developed for evaluating next-generation wireless network protocols. The Cell-Lab is being designed to support virtualization to enable multiple experiments simultaneously on top of femtocell base stations. In addition, open and remote access to the testbed, and integration with wired testbeds will be considered as basic features. To this end, our novel implementation strategy for achieving these goals and Cell-Lab's usage scenarios are described.

Introduction

As the expansion of the Internet is exposing limitations in terms of scalability, mobility, security, and so on, the network community is encouraged to make an effort to redesign the Internet architecture fundamentally. To facilitate the evaluation of new proposals, many network testbeds have recently developed either for wired networks (e.g., PlanetLab [1], VINI[2], Emulab[3]) or for wireless networks (e.g., ORBIT[4], MIT Roofnet [5]). Each wireless testbed is targeted on a specific access network such as mesh network or ad-hoc sensor network.

Unfortunately we found that wireless testbeds have a limited spectrum of radio technologies. Even though cellular networks (e.g. 3G) is popular worldwide and WiMAX is emerging rapidly, all the current testbeds are exploiting the same wireless access based on IEEE 802.11 series protocol. For example, the ORBIT testbed consists of nodes equipped with 802.11a/b/g wireless cards from Atheros and Intel chipsets. This situation comes from the fact that it is quite costly and infeasible to construct 3G or WiMAX base stations for network research testbed.

In this paper, we argue that the network community needs research testbeds for mobile wireless networks based on various radio access technologies, and introduce a new wireless testbed, dubbed Cell-Lab, which is currently being developed based on cellular radio access. To resolve the cost problem stated above, the Cell-Lab adopts the user-deployable femtocell base station, which is originally designed as a small base station covering a few tens of meters. Because of its low cost and small coverage, femtocell base stations are adequate and feasible to be used to construct a testbed. Especially, we focus on UMTS networks due to the fast standardization of femtocell base stations. In addition, some UMTS femtocell prototypes incorporate not only base station functionality but also Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN) functionalities. Thus, by using UMTS femtocell base stations, it is possible to set up an independent private cellular network without constructing a cellular core network or leasing from a cellular service provider.

Testbed Architecture

This section presents three design goals of Cell-Lab, and overviews the high-level architecture of Cell-Lab including our novel strategy for base station virtualization. We also sketch out potential usage scenarios.

Design Goals

To outline the testbed we are proposing, the key design goals adopted for our testbed are summarized as follows:

- **Providing open-access to remote users:** Although Cell-Lab can be used in an independent and private manner without opening its access outside, it is being designed as an open testbed that can be accessed from a remote area; thus playing an important role in the research community. Experimenters are granted to run their protocols and softwares on the testbed just like PlanetLab. As drawn in Fig. 1, Cell-Lab sites can have a connection with the Internet, and remote researchers may carry out experiments by accessing

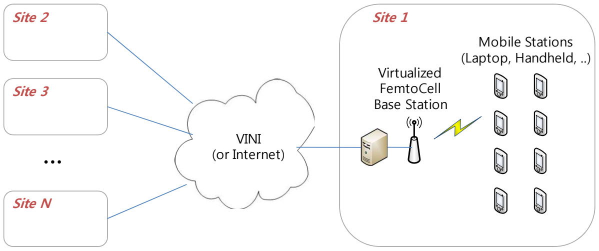

Figure 1. Cell-Lab sites can be connected via Internet, and will be integrated with wired testbed e.g. VINI.

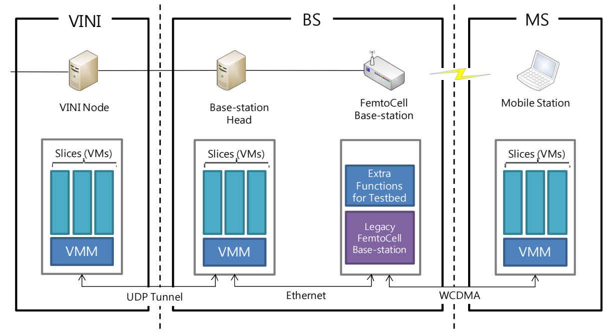

Figure 2. Cell-Lab implementation scenario. Separate base station head virtualizes femtocell base station.

through the Internet. To fully utilize the testbed remotely, in addition, it should be capable of unmanned operation. For example, researchers should be able to schedule communication between a base station and a set of mobile nodes, and dictate how the base station and mobile nodes be configured.

- **Supporting simultaneous experiments:** Cell-Lab should support multiple experiments simultaneously to reduce the cost of installing and running the physical infrastructure. In addition, running several experiments at the same time permits researchers to experiment with different protocols and services together. Cell-Lab is expected to achieve this goal by virtualizing a base-station. A physical base-station supports multiple virtual base-stations which are provided with their own isolated resources (*e.g.*, CPU, bandwidth, memory, and storage) so that the abnormal operation of one experiment does not affect adversely the operation of other experiments running on the same base-station. In addition, since the maximum number of simultaneous mobile stations supported by a typical femtocell base station prototype is limited to a small number, virtualizing mobile stations can increase the maximum number of simultaneous mobile stations; thus alleviating the limitation.

- **Interworking with existing wired testbeds:** Cell-Lab should be designed to provide global-scale experiments with customized topologies by interworking with existing wired testbeds like VINI. Using the integrated platform, researchers will be able to emulate real network topologies involving wired nodes at VINI sites worldwide and wireless nodes at the Cell-Lab facility.

Architectural Plan

The Cell-Lab testbed consists of two types of wireless components: base stations and mobile stations, both of which serve as the primary platform for user experiments. Both parties are equipped with cellular radio interfaces (WCDMA) and virtualized to support multiple experiments simultaneously. In a base station component, a femtocell base station with a WCDMA radio interface will be used. As a mobile station, any equipment capable of connecting a WCDMA USB modem can be used such as laptop computer.

The base station component in Cell-Lab includes a customized femtocell base station and its virtualized controller as shown in Fig. 2. Since the femtocell base station is originally targeted on the residential market, it is designed with low hardware capability; thus implementing virtualization functionality inside almost infeasible. Instead of virtualizing the femtocell base station directly, we introduce a separate controller, called *a base station head*, that performs virtualization and controls the femtocell base station via one of its network adaptors.

Upon the off-the-shelf UMTS femtocell implementation which includes not only Radio Access Network equipments (i.e., Node-B and Radio Network Controller) but also Core Network equipments (e.g., SGSN, GGSN and IP Multimedia Subsystem User Equipment (IMS UE)) [1], we plan to add the following features. To construct a private cellular network independent of a UMTS service provider, self-authentication logic will be implemented in IMS-UE, and Universal Subscriber Identity Module (USIM) inside a WCDMA USB modem that is connected to mobile stations is configured with a pre-determined secret key for testing.

[1]This kind of configuration is so called semi-IMS model in UMTS femtocell field.

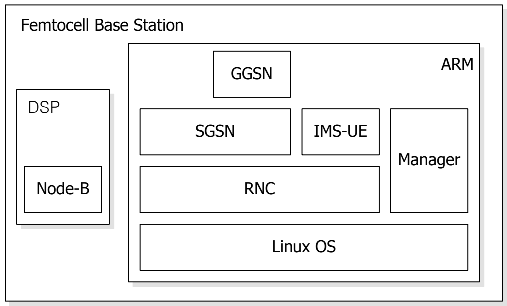

Figure 3. Architecture of femtocell base station. Its components include Node-B, RNC, SGSN and GGSN.

To regulate the network bandwidth which is allowed for an experimenter, a bandwidth control function is necessary. Cell-Lab is going to regulate the network bandwidth for each Packet Data Protocol (PDP) context [2]. Moreover, a Simple Network Management Protocol-like protocol will be defined in order for the base station head to interact with the femtocell base station. Using this protocol, the control information to configure the femtocell base station and the measurement data collected at the femtocell base station are conveyed between the base station head and the femtocell base station.

A Cell-Lab site may interwork with a wired testbed e.g., VINI, if necessary. One natural approach is establishing a virtual link between Cell-Lab and VINI using a UDP tunnel. In addition, a routing module for constructing a customized global topology will be necessary. The detailed mechanism for integrating the Cell-Lab with a wired testbed is under discussion.

Virtualization

For supporting multiple experiments simultaneously, Cell-Lab supports a virtualized base station. More precisely, the virtualization function is being implemented at the base station head, instead of virtualizing femtocell base station directly due to its low hardware capacity. Like PlanetLab, we are working with the Linux VServer implementation [6] to provide root access to Cell-Lab users for development purposes while isolating users from each other. As shown in Fig. 4, the base station head runs VServer for virtualization. Based on Linux VServer, multiple virtual machines are created on a base station head. Each virtual machine runs its own operating system and applications with isolation. Thus, abnormal operation of a virtual machine does not affect the other virtual machines.

[2]A PDP context is a range of settings that is activated when a mobile station accesses the Internet.

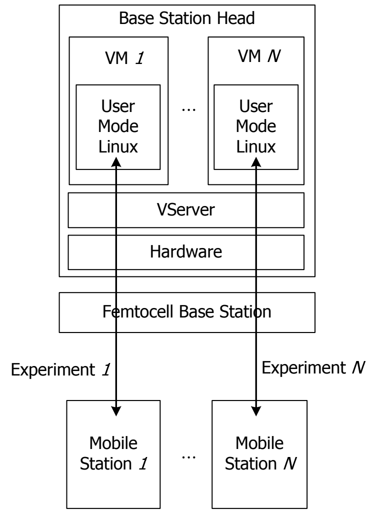

Figure 4. Cell-Lab reference model. VServer runs on the base station head.

In addition, we are working with User Mode Linux [7]. User Mode Linux is a full-featured Linux Kernel, and runs as a process in user space. It starts from within the virtual machine of the base station head, and creates a complete virtual environment with network devices and a file system. We make use of User Mode Linux in order to make a development process faster because we are able to debug User Mode Linux like any normal Linux process.

Usage Scenarios

We give some example experiments which can be conducted on the Cell-Lab, to illustrate its potential usages.

- **Transport-layer protocols for cellular:** Although a number of transport layer protocols have been studied for the cellular network in the literature [8][9], most of them tend to be evaluated using simulations which excessively simplify the real physical channel. Cell-Lab is expected to be used as an easily available tool for evaluating or prototyping new transport-layer protocols proposed for wireless/mobile networks. In addition, as classified in [9], new TCP enhancement schemes can be grouped into three groups: end-to-end proposals, split-connection proposals, and link-layer proposals. Among them split-connection schemes have rarely studied experimentally since it is hard to modify the implementation of base station in actuality. Cell-Lab allows experimenters to implement the splitting point at the base station head, instead of modifying the femtocell base station.

- **Scheduling algorithms at base station:** A scheduling algorithm plays an important role in the provision of quality of service such as delay or throughput guarantee. The design of scheduling for mobile network is especially challenging because the link quality is highly variable due to mobility of mobile stations. Cell-Lab may be used for evaluating scheduling algorithms at the base station by implementing programmable queues inside the base station head, instead of modifying the H/W queue of femtocell base station. The frame processed by scheduling algorithm at the base station head will be forwarded to the femtocell base station which has a single FIFO queue, as similarly tried in [10]. In principle, scheduling function should be implemented inside the MAC controller. However, the MAC controller cannot be modified by people other than the corresponding chip vender.
- **Handover mechanisms:** A horizontal handover process transferring ongoing calls from a cell to another, or a vertical handover where a mobile station switches between different access networks such as from a 3G network to a WLAN has been important research issues as mobile networks become popular. Multiple Cell-Lab sites can be deployed with overlapping coverage to evaluate handover algorithms. Since a typical femtocell base station has a small coverage (about 30 meters) due to limited transmission power, we can easily make a handover situation. In addition, Cell-Lab may interwork with existing testbeds with different radio access e.g., WLAN testbeds for implementing and evaluating heterogeneous handover protocols.

Conclusions

This paper introduced a cellular-based wireless testbed which is being developed using UMTS femtocell implementation, and explained its design goals and overall architectural plan. Our testbed is expected to be used for evaluation of various network protocols including transport layer protocol for cellular, scheduling algorithm at base station, handover mechanisms, and so on. To overcome the limited capability of current femtocell base stations, we propose to implement virtualization functions with an additional entity which is the base station head, so that multiple experimenters can run their own protocols at the same time.

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