BeamViewer: Visualization of Dynamic Antenna Radiation Patterns using Augmented Reality

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***Abstract*—Wireless research and education are often hindered by the fact that RF electromagnetic signals are invisible and therefore hard to visualize. Domain-specific software, such as those used for antenna radiation pattern measurements, has significantly enhanced the level of radiation visualization through interactive 3D plots. However, the intuition stops there and does not carry over into the real-word operational environment of antennas and radios. As a result, there exists a real disconnect in visualization between the available antenna radiation patterns and their effects on wireless network performance. In this demo[1] we present BeamViewer, an augmented reality framework to help visualize and capture the dynamic radiation patterns of reconfigurable antennas in real time. BeamViewer takes inputs from the cognitive radios controlling beam-steerable antennas and annotates on a live-view mobile screen the active pre-measured radiation patterns. This capability adds an unprecedented level of instant visualization and provides valuable insights into the dynamics of a reconfigurable antenna-based cognitive radio network.**

I. Introduction

Wireless research and education are often hindered by the fact that RF electromagnetic signals are invisible and therefore hard to visualize. Without a physically intuitive way to visualize signals as they propagate through the medium, wireless transmissions often go unaccounted for, and we resort to mathematical analyses or after-the-fact observations to gain a better understanding of wireless network dynamics. In our own work investigating small-cell interference mitigation techniques using reconfigurable antennas and clean-slate wireless research platforms [1], we observe the need for dynamic visualization of the antennas' radiation patterns and beam directions in real time. Such insights are particularly helpful in the algorithmic verification and interpretation of experimental results, especially in mobility-based experiments.

The radiation pattern of an antenna is traditionally measured in an anechoic chamber through an extensive process using highly specialized equipment. Alternatively, simulated three-dimensional polar plots of antenna gains can be generated in domain-specific software such as HFSS from Ansys [2]. While these plots offer a tremendous level of visualization of antennas' performance, they exists solely in software and are not linked to the radio platforms on which antennas operate. To make matters worse, reconfigurable antennas can assume a number of different radiation patterns, selectable on the fly by the underlying cognitive radio. As a result in cognitive radio networks enabled by reconfigurable antennas, there exists a disconnect between the available radiation patterns and their effects on network performance. In this work we seek to bridge this gap and extend the usefulness of costly antenna pattern measurements beyond offline records with a system that allows instant visualization of these patterns during operations.

[1]Demo video available at `https://youtu.be/saOKWRpYyXo`

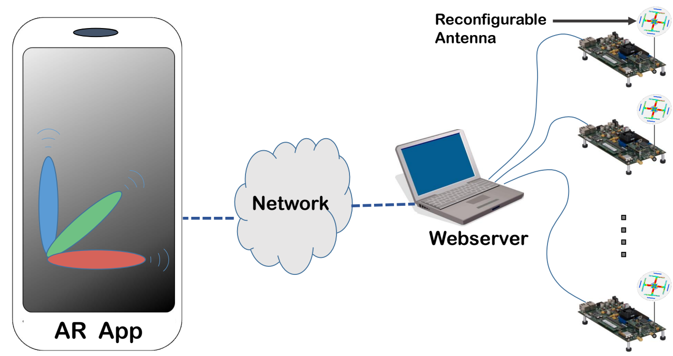

Fig. 1: BeamViewer system architecture

Augmented Reality (AR) is a subset of Mixed Reality (MR) that enables seamless integration of real-world environment and computer-generated objects in real time. Recent advances in hardware and software for mobile computing have boosted the ubiquity of AR and brought about many emerging applications, not limited to only vision but also encompassing all other senses such as touch and hearing. However, AR has not found many applications in the context of wireless connectivity, mainly due to the difficulty of sensing and observing high-speed wireless signals in real time. The closest application we can find is described in [3], where AR is employed to visualize signals emanating from wireless routers and distant cell towers, albeit using historical data and not updating live.

To further illustrate the usefulness of AR for wireless applications, we present BeamViewer, an augmented reality framework for dynamic visualization of reconfigurable antennas' radiation patterns. BeamViewer collects real-time statistics on antenna configurations and link throughputs from an underlying cognitive radio network and depicts them visually on mobile devices. BeamViewer is highly extensible to aid in the comprehension of of future wireless network dynamics.

II. System Implementation

BeamViewer's real-time visualization system is a combination of mobile computer vision, interactive game play, and a web framework. While the underlying cognitive radio network is not necessary for BeamViewer to function, the radios are what actually control the antennas and supply useful real-time information on selected antenna patterns and achieved network throughputs. Without the antenna state selection logic from the cognitive radios, BeamViewer only displays static antenna radiation patterns that add little to the overall picture. An overview of the complete system is depicted in Fig. 1.

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Fig. 2: BeamViewer mobile frontend. The blue and green antenna beams are annotated by the AR toolkit and correspond to pre-measured antenna radiation patterns.

A. BeamViewer Mobile Frontend

BeamViewer's frontend builds upon Qualcomm's Vuforia mobile AR toolkit and the Unity game engine. The AR toolkit is responsible for the framework's integration with the real world, while Unity controls the dynamics of virtual objects including the antenna patterns. We set up the BeamViewer mobile application internally as a Unity game scene. The scene dynamics happen entirely inside the game engine and are displayed to a mobile screen through the viewpoint of a *camera object*. Besides cameras, a scene can also contain *game objects*, such as characters or terrains, and *light objects*, which control and cast light onto the scene. A special `ARCamera` object, available through the Vuforia plugin for Unity, enables the use of devices' cameras as viewpoints into the game scene and effectively blend the real and virtual worlds.

Reconfigurable antennas are detected spatially through physical image markers placed directly below them. These markers correspond to game objects with clearly defined positions in the Unity scene. We once again leverage Vuforia's APIs to perform object recognition. Once the antennas are detected by the Unity engine, we can add pre-existing 3D radiation pattern objects at relative offsets to the image markers and dynamically control them through game action scripts. The 3D antenna pattern objects were previously extracted from HFSS after measurements and imported into Unity as game objects. At this point we can connect to BeamViewer's web backend and transform the radiation patterns based on real-time inputs from the predominant cognitive radio link. The update frequency is configurable and currently set at 10 times per second. A snapshot of the mobile frontend is shown in Fig. 2.

B. BeamViewer Backend

BeamViewer's backend consists of the actual cognitive radio nodes that control the reconfigurable antennas, as well as a central webserver to collect and serve real-time antenna pattern information and network metrics. Our system employs the planar Reconfigurable Alford Loop Antenna with integrated control circuitry [4], designed by Drexel Wireless System Laboratory. To control the antennas, we develop a directionality-based cognitive network on the Wireless open-Access Research Platform (WARP) [5]. Our implementation leverages WARP's real-time 802.11 physical layer and a custom TDMA-style MAC with machine learning logic for selecting favorable antenna states to boost link performance. The central webserver, implemented in Python, communicates with the radio nodes via serial COM ports to collect latest antenna and throughput data. Specific information for each network node can then be served through dedicated web URLs. BeamViewer's frontend continuously polls these URLs to capture and update the network-wide antenna configurations.

III. Extending BeamViewer

This demo is an early experiment with applying augmented reality to visualize some aspects of the invisible wireless technologies that connect us. We develop BeamViewer as a modular framework that can be extended to provide insights into a wide range of network activities. Our plan is to extend BeamViewer into a well-rounded visualization suite for wireless education and research. As such, BeamViewer can be used to observe network dynamics, monitor spectrum usage, detect adversarial activities, and conduct interactive spectrum games. Leveraging the increasingly sophisticated sensors and cameras of mobile devices, we can devise more intuitive and user-friendly methods to interact and control wireless signals.

IV. Demonstration

We demonstrate BeamViewer in a real-time setting with two cognitive radio nodes, both equipped with reconfigurable antennas, communicating in a WiFi channel. A third radio will be set up to turn on and off at times to generate downlink and uplink interference in the channel, thereby forcing the cognitive radios to adapt their antenna patterns to improve link throughputs. The audience can use push buttons on the WARP radios to switch antennas between the forced omnidirectional mode and dynamic, radio-controlled, directional mode with four possible beams. Link throughputs will be plotted on a monitor screen at all times to observe the effects of different antenna radiation patterns. The BeamViewer mobile app is pre-installed on several mobile devices and set up to display real-time antenna patterns from each radio node. The audience can therefore instantly observe when the antenna patterns change.

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