eStadium – The "Living Lab"

Xuan Zhong, Hoi-Ho Chan, Timothy J. Rogers, Catherine P. Rosenberg and Edward J. Coyle
The Center for Wireless Systems and Applications (CWSA)
Purdue University, West Lafayette IN 47907-2035
{zhongx, hchan, tjrogers, cath, coyle}@purdue.edu

***Abstract*—We provide an overview of the *eStadium* WLAN testbed in Purdue's Ross Ade stadium. This research testbed supports wireless delivery of web-based "infotainment" applications to fans' handheld devices. These applications include view-on-demand of video clips of important plays accumulated as a game progresses. By using various wireless LAN measurements and server logs, we have studied video streaming performance in this wireless setting and characterized the relationship between wireless LAN channel conditions and user-perceived quality-of-service. Measurements from the 2004 and 2005 football seasons are given. Potential improvements of the current implementation are proposed and future research directions are discussed.**

***Index Terms*— Wireless LANs, Video Delivery, Mobile Users, Location-dependent Admission Control**

I. Introduction

THE increasing popularity of Wireless LANs makes 802.11 infrastructures good candidates for the development of multimedia applications that users can access via PDAs, Wi-Fi enabled smart phones, and other wireless devices. Successful development of these applications is, however, a significant challenge because of 802.11's characteristics and the limitations of these small mobile devices. These include high bit-error rates, dynamic channel conditions, power constraints, limited storage, etc.

The effect of the wireless channel's characteristics on the performance of multimedia applications needs further investigation in order to develop the best approach to the distribution of multimedia content over a time-varying channel. These further studies can facilitate the design of an advanced wireless video delivery system with technologies such as data-rate adaptation, adaptive bandwidth allocation, and intelligent admission control.

To carry out these further studies, we have built a "real-world" testbed that includes wireless infrastructure that has been installed throughout Purdue's Ross-Ade Stadium. The experiments performed in this testbed include measurements of the behavior of fans and of the video streaming application they access via their wireless devices. This testbed with real users in a real sports venue is called the *eStadium Living Lab* [1][2].

II. The E-Stadium "Living Lab"

A. Brief Overview

Purdue's *eStadium* project is part of a campus-wide living laboratory for the study of wireless communications. Traditionally, experimentation is carried out in a laboratory. However, to facilitate real-world, hands-on learning and experimentation by students, Purdue University has created the concept of a "living laboratory." The living laboratory uses the "city" of Purdue University as a unique space for experimentation while still serving in its traditional role.

eStadium is a collaborative partnership consisting of the Center for Wireless Systems & Applications (CWSA), Information Technology at Purdue (ITaP), and Purdue Intercollegiate Athletics. The focus of *eStadium* is the creation of a "living" laboratory at Purdue's Ross-Ade Football Stadium by: (1) equipping it with an 802.11b based wireless network, and (2) designing a set of exciting applications for game day use by football fans and wireless researchers. A fully functional *eStadium* application system is available for trial at http://estadium.purdue.edu/estadium.

During games, users are provided with wireless PDAs (they may also bring their own PDAs or smart phones) to enjoy applications such as video clips of instant replays, up-to-the-minute game statistics, player and coach biographies, and other wireless "infotainment" services. In addition to providing interactive content to the fans, *eStadium* provides practical, real-world learning experiences for students involved in the project. Within the unique scope offered by the university environment, students can develop, deploy, and test next generation wireless systems, applications, and technologies.

B. Wireless Network Infrastructure

Wireless coverage in Ross-Ade Stadium is provided by 19 Cisco Aironet 1200 APs. Users associate with the "estadium" SSID and get class C private IP addresses from the *eStadium* DHCP server. They can only access the *eStadium* wireless network, which is an open network without any authentication or encryption.

A logical layout of the *eStadium* wireless network is shown in Fig. 1. The APs are connected to switches located on each floor of the stadium, which are then connected to the main router in the stadium. The packets from the *eStadium* VLAN are routed only to the *eStadium* servers, which consist of a DHCP server, two identical content servers, a video server, and a set of load balancing computers to isolate the content servers from Denial-of-Service attacks.

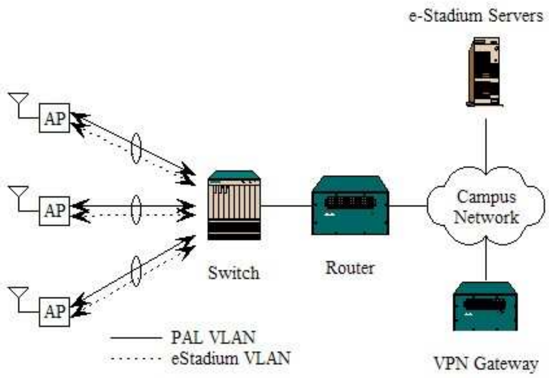

Fig. 1: *eStadium* wireless network logical layout

C. Implementation of the Video Distribution System

The *eStadium* video distribution system's architecture is shown in Fig. 2. The approach currently used for video distribution is unicast Video-on-Demand (VOD). This is not scalable because an access point can be overloaded with traffic as the number of associated users increases. When the channel usage is approaching its maximum, video quality will degrade or network connections will be dropped. Since all the clients associated with one AP share the same transmission medium, this kind of performance degradation is seen by all of the clients, not just one. The wireless users can also roam from one AP to another, which requires a location-dependent admission control mechanism in order to limit video traffic on a per-AP basis.

In the current implementation, a Location Discovery System (LODS) is used to find the AP for a given device. It uses syslog messages to locate a device - finding which AP it belongs to based on its IP address. The location detection process only uses the system log messages sent by the DHCP server and access points to locate a device. Syslog messages from the APs provide the MAC-to-AP mapping. Syslog messages from the DHCP server provide the MAC-to-IP mapping. These messages are stored in two different tables in an SQL server database. We then join these two tables to get the IP-to-AP mapping in real time.

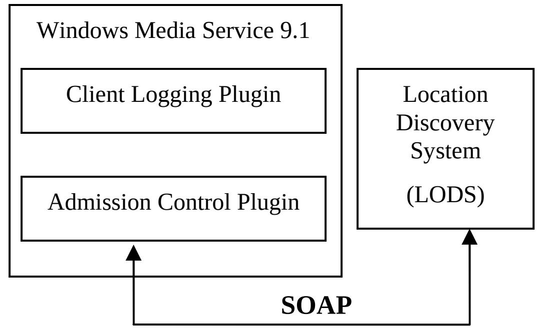

Fig. 2: eStadium video distribution system architecture

The admission control plugin is used to limit the video traffic on each AP. It is implemented as a custom plugin under Window Media Services 9.0 SDK. It runs as a Windows service on the video server and communicates with LODS using the Simple Object Access Protocol (SOAP).

D. Data Collection and Results

We used four techniques to trace WLAN usage and video streaming performance: Syslog messages, SNMP polls, wireless sniffers, and client receive logs.

Fig. 3 shows the empirical CDFs for the number of roams for each 2005 home football game. Clearly, user behavior is similar across games.

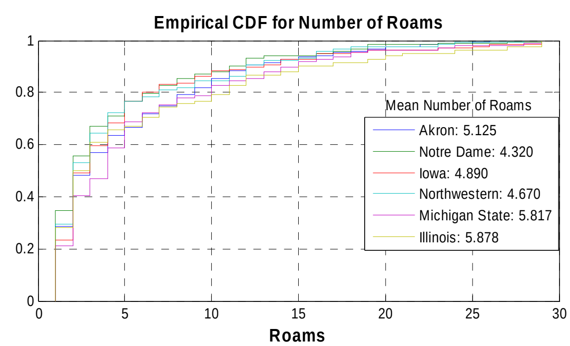

Fig. 3: Empirical CDF of roams

Windows Media Services 9 series supports client receive logs. The client receive log indicates how the client received the video files. In our database on the video server, we record every client's streaming entries with detailed client receive logs, such as the average bandwidth at which the client is connected to the server, number of packets from the server that are received correctly on the first try, number of client requests to receive new packets using UDP resend, number of packets recovered after being resent through UDP, etc.

Fig. 4 shows results of video streaming performance per AP for the 2005 Northwestern-Purdue game. The

APs’ physical locations on each floor of the stadium are mapped to this 3-D plot. The bars along y=0 are for the 1’st floor; along y=3 for the 2’nd floor, etc. The yellow bars show the actual values for one game; the green bars show the average for all games. Note that the number of video requests in each game only reflects the requests with complete playback. We didn’t count requests that were aborted during video playback by the user or by loss of the network connection.

The number of UDP resend requests, which is shown for each AP in Fig. 4(b), is high when the video streams being delivered through those APs are suffering high error rates because of congestion. The congestion is made worse by the resending of lost packets, which is documented in Fig. 4(b) as the number of resend requests and in Fig. 4(c) as the number of recovered packets via resend requests.

The initial cause of the congestion is the use of bandwidth by another VLAN that is supported by the same APs. We do not yet have information on traffic on that VLAN that could be used by a more advanced admission control algorithm to ensure high quality video delivery.

III. Discussion

Based on our experiments, the number of “UDP Resend Requests” is a good measure of client-perceived wireless network conditions. It is the number of times that clients ask the Windows Media Services Server to resend data packets. It may be high when the server cannot reliably send packets via UDP. Thus, it is a good indicator of system overload.

Information regarding real-time network conditions, such as the packet loss rate and the video playback rate at the client, can be obtained from Windows media streaming client logs. This information can be used to implement an adaptive admission control scheme that reflects the dynamic channel conditions. This will enable us to make better use of the channel’s capacity.

Since Cisco Aironet 1200 series APs support 802.11e, we would also like the admission control module to use client feedback to dynamically manipulate the 802.11e QoS parameters to improve the QoS for the clients associated with each AP.

One major problem in the current *eStadium* video distribution system is that it is not scalable. One possible solution is to use a hybrid operation mode that allows clients to switch to the ad-hoc operation mode of 802.11 when the AP is approaching its channel capacity. In this case, it is favorable to let the clients form transient ad hoc networks, transfer video files locally, then switch back to infrastructure mode.

References

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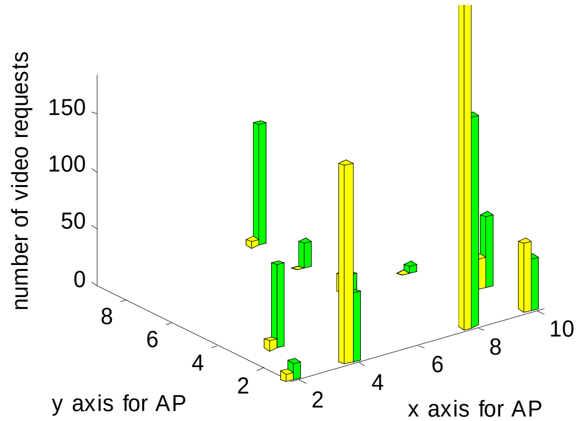
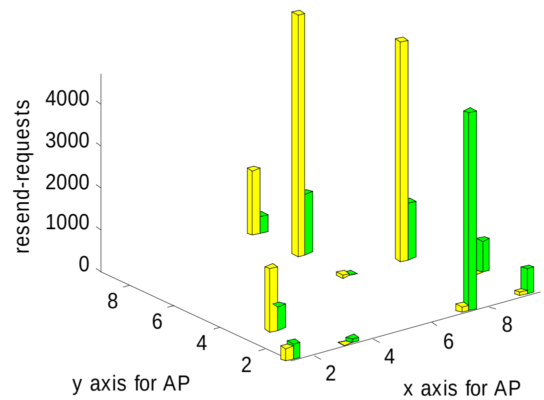
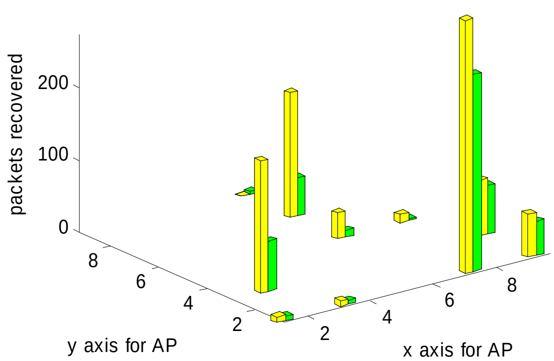


(a) Number of video requests



(b) Number of UDP resend-requests



(c) Packets recovered via UDP resend-requests

Fig. 4: Video streaming results for one football game.