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Video Streaming over Wireless Mesh Networks

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Abstract *– Wireless mesh networks (WMNs) have emerged as a key technology for next-generation wireless networking. Wireless mesh network is a self-organizing, self-managing and self-healing and thus it is easy and speedy in deployment. Apart from these characteristics, it is low cost and easy maintenance. However, WMNs pose several difficulties in transmission of information, especially time critical applications, such as streaming video. In this tutorial we provide focuses on WMNs and their prominence on ad-hoc networks, concepts of video and its transmission requirements, such as video coding and wireless channel specifications, with focuses on video surveillance systems.*

Keywords*: Wireless mesh network; Client; Router; Video, Compression*

ORIGINAL ARTICLE

INTRODUCTION

Wireless mesh networks are wide spread acceptance mainly because of their fault tolerant ability against network failures, simplicity in setting up the network and they have broadband capabilities. Unlike telephone tower, where failure of single mobile tower affect users of a large geographical areas, wireless mesh networks performs well even with the failure of few nodes. Wireless mesh networks are dynamically self-organized and self-configured, with the nodes in the network automatically establishing an ad-hoc network and maintaining the mesh connectivity. WMNs are comprised two types of nodes: mesh routers and mesh clients. Other than the routing capability for gateway/bridge functions as in a conventional wireless router, a mesh router contains additional routing functions to support mesh networking. Through multi-hop communications, the same coverage can be achieved by a mesh router with much lower transmission power.

Mesh routers have minimal mobility and form the mesh backbone for mesh clients. Thus, although mesh clients can also work as a router for mesh networking, the hardware plat-form and software for them can be much simpler than those for mesh routers. For example, communication protocols for mesh clients can be light-weight, gateway or bridge functions do not exist in mesh clients, and only a single wireless interface is needed in a mesh client and so on.

In addition to mesh networking among mesh routers and mesh clients, the gateway/bridge functionalities in mesh routers enable the integration of WMNs with various other networks. Conventional nodes equipped with wireless network interface cards (NICs) can connect directly to WMNs through wireless mesh routers. Customers without wireless NICs can access WMNs by connecting to wireless mesh routers through, for example, Ethernet. Thus, WMNs will greatly help users to be always-on-line anywhere, anytime. Consequently, instead of being another type of ad-hoc net-working, WMNs diversify the capabilities of ad-hoc networks.

Generally, the video delivered to wireless users is either live video, e.g., the live coverage of a sporting event, concert, or conference, or prerecorded (stored) video, e.g., a TV show, entertainment movie, or instructional video. Some videos fall in both categories. For instance, in a typical distance learning system, the lecture video is available to distance learners live, i.e., while the lecture is ongoing, and also as stored video, i.e., distance learners can request the lecture video later in the day or week from a video server.

The rest of this paper is organized as follows. In section 2, we introduce the architecture of WMNs. In section 3 digital video requirements is presented. Section 4 describes challenges of delivering video in wireless networks. Different types of video streaming in WMNs are discussed in section 5. In section 6 a typical WMN for education is presented. Finally, section 7 concludes paper.

WIRELESS MESH NETWORK ARCHITECTURE

In Wireless Mesh Networks (WMN), nodes are comprised of mesh routers and mesh clients. Each mesh node operates not only as a host but also as a router, forwarding packets on behalf of other nodes that may not be within direct wireless transmission range of their destination [1]. A Wireless Mesh Network (WMN) can be designed in three different network architectures based on the network topology: client (flat) WMN, infrastructure/backbone (hierarchical) WMN, and hybrid WMN. In the following we describe each of these topologies.

Client WMNs.

Client meshing provides peer-to-peer networks among client devices. In this type of architecture, client nodes constitute the actual network to perform routing and configuration functionalities as well as providing end-user applications to customers. Hence, a mesh router is not required for these types of networks. Thus, a Client WMN is actually the same as a conventional ad hoc network. Fig. 1 shows a typical Client WMN.

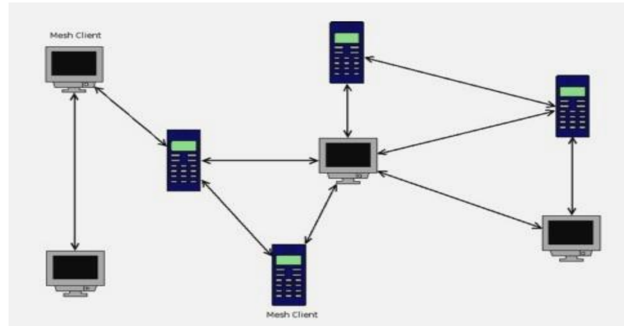
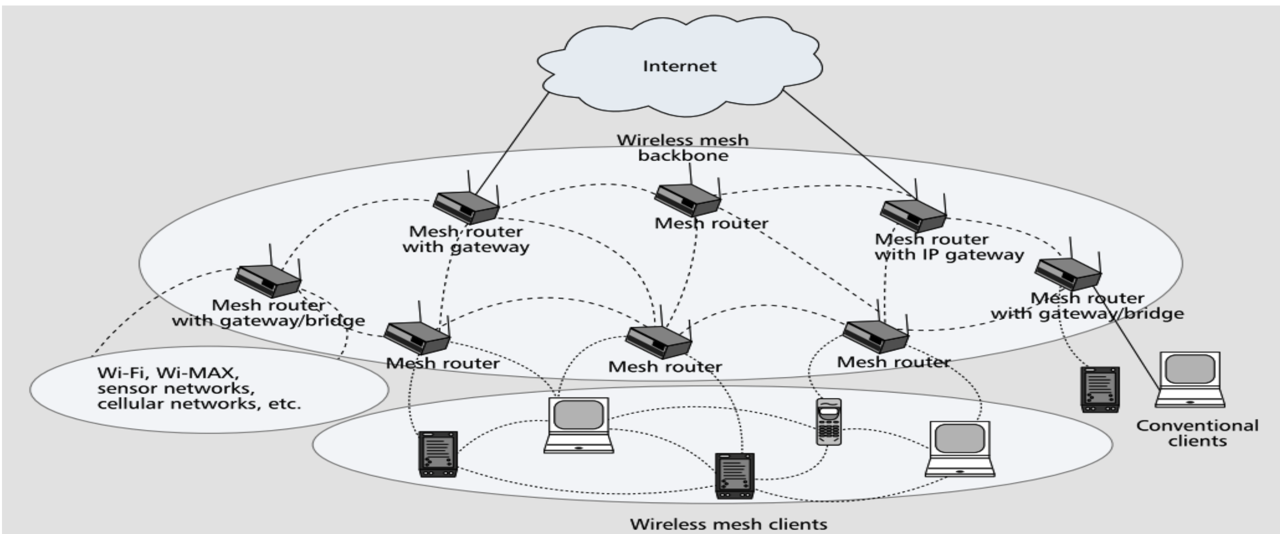
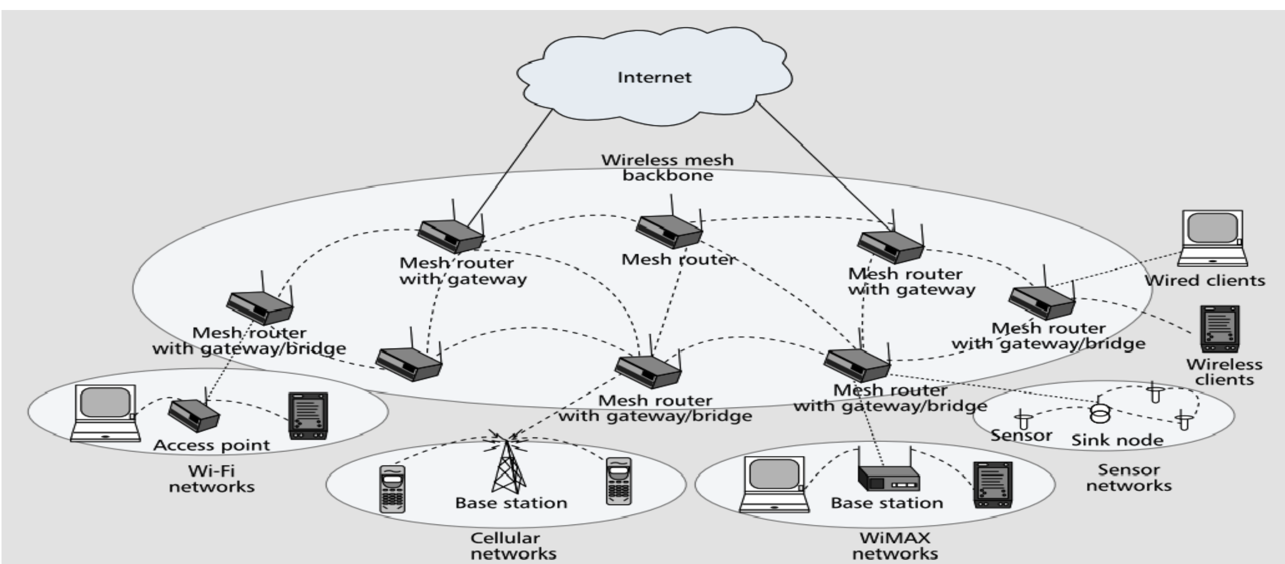


Figure 1. Client wireless mesh network





Infrastructure/Backbone WMNs

In this architecture, mesh routers form an infrastructure for clients, as shown in Fig. 2, where dashed and solid lines indicate wireless and wired links, respectively. The WMN infrastructure/backbone can be built using various types of radio technologies, in addition to the mostly used IEEE 802.11 technologies. The mesh routers form a mesh of self-configuring, self-healing links among themselves.

With gateway functionality, mesh routers can be connected to the Internet. Conventional clients with an Ethernet interface can be connected to mesh routers via Ethernet links. If different radio technologies are used, clients must communicate with their base stations that have Ethernet connections to mesh routers.

Hybrid WMNs.

This architecture is the combination of infrastructure and client meshing, as shown in Fig. 3. Mesh clients can access the network through mesh routers as well as directly meshing with other mesh clients. While the infrastructure provides connectivity to other networks such as the Internet, Wi-Fi, WiMAX, cellular, and sensor networks, the routing capabilities of clients provide improved connectivity and coverage inside WMNs.

The characteristics of WMNs are outlined below, where the hybrid architecture is considered for WMNs, since it comprises all the advantages of WMNs:

- WMNs support ad hoc networking and are self-forming, self-healing, and self-organization.
- WMNs are multi-hop wireless networks, with a wireless backbone provided by mesh routers.
- Mesh routers have minimal mobility and perform dedicated routing and configuration, which significantly decreases the load of mesh clients and other end nodes.
- Mobility of end nodes is supported easily through the wireless infrastructure.
- Power-consumption constraints are different for mesh routers and mesh clients.
- WMNs are not stand-alone and need to be compatible with other wireless networks.

Mesh Networks Versus Ad-hoc

Ad-hoc network is generally designed for high mobility multi-hop environment; on other hand, a WMN is designed for a static or limited mobility environment [19]. Therefore, protocols designed for ad-hoc networks perform badly in WMNs. In Table 1, some differences between WMNs and ad-hoc networks are mentioned.

Table 1
Difference between Ad-hoc networks and mesh networks.

Issue	Ad-hoc Network	Mesh Network
Network Topology	Highly Dynamic	Relatively Static
Energy Constraints	High	Low
Relaying	by mobile nodes	by static nodes
Routing	On-demand	Pro-active

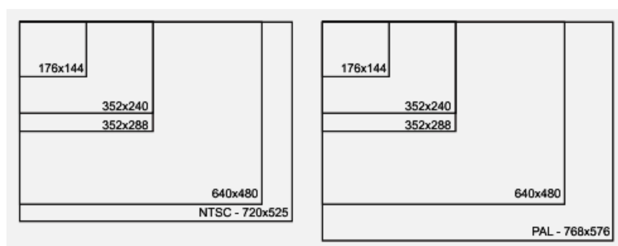
From the Table 1, it can be seen that primary difference between ad-hoc networks and WMN is mobility. As the nodes change their position rapidly, pro-active routing protocol fails to find the appropriate route. Thus, on-demand routing protocol is used in ad-hoc networks. Due to fixed relay nodes, of WMN, most WMNs have better energy storage and power source.

Digital Video Network Requirements

In a video application, the network must be capable of carrying the aggregate throughput required to deliver the packetized video streams being generated by all of the cameras. Assuring adequate packet throughput performance can require a substantial amount of bandwidth to accommodate the total, end-to-end traffic load. While one thinks of traffic in a video network as being all 'upstream', that is, from the cameras to the screens, it's actually two-way. PTZ (pan-tilt-zoom) cameras require two-way traffic, of course, in order to receive operator commands. The network protocols themselves are also two-way. Cameras are typically viewed using a browser-based interface; such connections are always two-way, even if the bulk of the low is upstream.

A. *Video Resolution*

Over the years, the computer and television industries have developed numerous resolution standards and acronyms. In digital video monitoring and surveillance applications, the cameras are based on standard video camera technology. Most cameras in use today offer the same resolution as standard television. HD cameras, offering the same resolution as HD TV, are also available. Fig. 4, illustrates the comparison between different video image sizes.



B. *Video Pixel Representation*

Monitors display pixels using a combination of Red, Green, and Blue (RGB). Most modern systems use an 8-bit value for each pixel; thus 24 bits or 3 bytes are required. This high degree of resolution is excessive. The human eye does not perceive color as sharply as it does overall brightness and detail. Thus, it is possible to reduce the amount of color in an image without a perceptible loss of quality. There are numerous schemes for this. A full analysis of these techniques is beyond the scope of this white paper. It's sufficient to note that in most cases a pixel can be represented with only 1.5 to 2 bytes, depending on the technique used.

C. *Video Frame Rate*

Some early video surveillance systems reduced the frame rate in order to reduce transmission requirements and video storage requirements. Frame rates were as slow as two frames per second. Because transmission and storage has improved dramatically, this is no longer necessary. While 30 frames per second is considered "full-motion", in most cases any frame rate greater than 20 frames per second appear life-like to the average viewer, and frame rates as low as 15 frames per second provide a reasonable simulation of motion.

D. Video Compression

A standard television image, consisting of 720 by 480 pixels, at 30 frames per second, represents a pixel rate of 720x480x30, or 10,368,000 pixels per second. For a full-color image, this represents a data rate of over 240 megabits per second. Happily, video compression technology dramatically reduces the required data rates. Using modern video compression techniques such as MPEG-2, MPEG-4, and others, high quality video, equivalent to a DVD, can be transmitted at rates as low as 10 Mbps. Low-quality video can be sent at rates around 100 Kbps, but this is not usually useful for surveillance activities.

There is another compression standard popular in surveillance applications, called Motion JPEG, or MJPEG. JPEG is a compression standard for use on still pictures, for example in a typical digital snapshot camera. Motion JPEG treats video as a series of still images. Each image is compressed individually; the sequence of compressed images is then transmitted with no further compression. While not as efficient as the MPEG standards, it does deliver sharper 'freeze-frame' images; useful in evidentiary applications.

E. *Calculating Digital Video Network Required Bandwidth*

The following equation can be used to determine bandwidth requirements for a single camera:

Raw Bandwidth = Width × Height × Pixel Depth × FPS (1)

Average bandwidth = Raw Bandwidth × Compression Factor (2)

Where

Width = frame width in pixels

Height = frame height in pixels

Pixel Depth = average number of bits per pixel

FPS = frames rate in frames per second

Compression Factor = the ratio of the compressed version to the original.

Challenges of Delivering Video in Wireless Networks

Delivering high-quality video surveillance over legacy wireless mesh networks was met with obstacles in the areas of performance, scalability, video quality, roaming and quality of service.

A. Limited Capacity

Mesh nodes may contain multiple radios, and the mesh nodes that use separate radios for client access and for wireless backhaul deliver better performance than single-radio nodes. However, with dual-radio nodes, the backhaul network still shares a single channel and requires omni-directional antennas. This results in congestion and degraded performance on each hop, which limits the size and performance of the mesh.

B. Common Video Impairments

Lost packets, out-of-sequence packets and jitter can visibly degrade video quality.

When video or voice packets are lost, the underlying user datagram protocol (UDP) cannot retransmit the lost or corrupted packets. And with compressed video, any amount of packet loss is noticeable. Packets can arrive at their destination in a different order than they were sent, usually because the route changed during a session. Jitter, or variable delay, causes the video quality to degrade with noticeable pixelation or blurring of the image. Jitter is caused by delay at the sender, variable data link rates along the path, changing traffic conditions, changes in routers, and roaming.

C. Seamless Roaming

Users and devices should be able to maintain their video stream, voice conversations and even data connections while moving from one mesh node to another – whether they are on foot or in vehicles.

D. Quality of Service (QoS)

Multiple user groups and multiple applications should be able to share the air. With QoS and traffic management, organizations can define and enforce service levels as appropriate.

Video Stream and Wireless Mesh Network

There are a variety of techniques for transmitting multimedia streams across a given wireless mesh network. In this tutorial we discuss three general areas that presented in [6]. These areas include path determination techniques, adaptive quality, and cross layer information gathering.

Path Determination Techniques

To transmit the data from the source to the destination requires the use of some form of path determination or routing algorithm.

One such technique utilized in [8] is congestion-minimized routing. Congestion-minimized routing tries, as its namesake suggests, minimizing the congestion which is defined as the average delay per link.

Authors [8] preset three different path selection algorithms with varying levels of estimation utilized: end-to-end, localized, and estimation based. For all algorithms they assume that the topology does not change during video transmission, and that there is no contention for access to the medium.

The end-to-end algorithm uses complete information of the network so it must first generate the connectivity structure P for each node which has data to transmit. P is defined as all possible paths from source to destination without loops. Using P they find the minimum cost path using an algorithm which exhaustively searches all possible paths. The algorithm then finds the path which has the smallest estimated timing requirements for transmission. The information needed for this is transmitted using separate logical communication links between nodes.

In localized estimation, only the link information of neighboring nodes is known. The rest of the path information is estimated based upon an approximation of several low layer data characteristics.

The third technique presented is purely estimation based and uses an estimation technique similar to the localized version; however, it does not even keep track of the information on links between the nodes.

The two peer-to-peer (P2P) algorithms are presented in [9], distributed collaborative and distributed non-collaborative. Both approaches assume that there is enough available bandwidth for an overlay layer for communication of the network conditions between peers.

In Table 2, comparison between different path determination techniques is presented.

Table 2.
Path determination overview

Technique	**Critiqued Areas**				
	Information complexity	Algorithmic Complexity	Network Overhead	Congestion Avoidance	Dynamic Adaption
Congestion minimized Routing	very good	very good	very good	very good	very good
End-To-End	very bad	very bad	very bad	very good	very bad
Localized	good	average	good	good	Very bad
Estimation based	very good	very good	very good	very bad	very bad
Distributed collaborative	average	good	average	very bad	very bad
Distributed non-collaborative	good	good	good	very bad	very bad

Adaptive Quality

Adjusting the quality of the video is a must for utilizing available bandwidth, and for reducing congestion throughout the network. A technique used in [8] is to minimize the distortion of the encoded video, while limiting the congestion introduced. They achieve this by estimating the tradeoff between increases in the rate and the decrease in the distortion. In [9], once a video is desired to be sent, the path provisioning scheme tries to find a path which meets the necessary requirements for the video transmission. If one cannot be found, it does not send the video stream.

Cross Layer Information

Most of the techniques discussed in [8] utilize information from the bottom three to four layers of the OSI model. The problem is how to gather this information so that the path determination and adaptive quality algorithms can make use of it. Paper [8] gathers the busy, block and idle times which are referred to as Tbusy, Tblock and Tidle respectively. They also keep a running average of the video payload size for each stream over the time period known as Bs. Paper [9] gathers information for each link in the network. It utilizes the modulation, the bit error rate (BER), and the guaranteed bandwidth. The modulation is defined by the physical medium, but there is no mention of how the modulation is gathered.

Introduce a typical Wireless Mesh Network for Education

In this section we give some brief review on WMN for education that presented in [10]. This system adopts the scalable video coding scheme that enables the video server to deliver layered videos to different user groups. In addition, in order to improve the robustness and efficiency of video streaming, a new approach was developed by transferring the important video control parameters by SDP at the beginning and RTCP during video transferring phase. Fig. 5 shows this WMN.

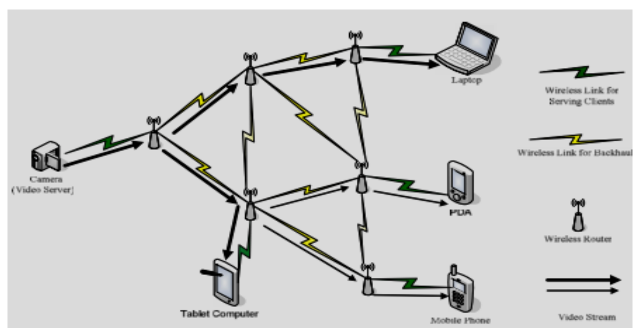


Figure 5. Network used for education.

Framework Design of Video Streaming

In this system a camera serves as a video streaming server. It is responsible for video capturing, encoding and transmitting real-time video streams. When end users want to receive the real-time videos, they send the requests to the server. The server returns the transmission information (multicast address and port number) and video parameters, such as Sequence Parameter Set (SPS) and Picture Parameter Set (PPS), to end users by Session Description Protocol (SDP) and then begins to transmit the real-time videos by multicast. After end users receive the necessary information, they can join the multicast group(s) to receive and replay the videos. If any user stops receiving the videos, it leaves the multicast group. If no one in the network receives videos, the server stops sending videos automatically, or it can be switched off manually.

TCP protocol is used on the transport layer to make sure SDP is error free. On server side, real-time videos are captured by Video for Linux (V4L) [5]. Then the captured videos are encoded by H.264/SVC, which supports scalable video coding. Before sending out by multicast, the encoded videos are encapsulated by RTP (Real-time Transport Protocol) to improve the reliability with the help of RTCP (RTP Control Protocol). On client side, after decoding, SDL (Simple Direct Media Layer) multimedia library is used to replay the videos [6]. On network layer, previously developed multicast AODV protocol is used for packet forwarding [3]. Since video transmission is time sensitive, UDP protocol is deployed on transport layer for streaming videos.

Transmission of Video Information

Video streaming has different characteristics comparing to common data transmissions over networks, so some special protocols have been developed to increase the efficiency of video streaming.

In an attempt to reduce the waiting time before playing the video and improve the reliability to transfer the important information, the video parameters information was added to the SDP message. The video parameters information consists of 3 types of packets: SPS, SPS Extension (SPSE) and PPS. During video transmission, since the video parameters may be changed, the SPS and PPS must be sent again. If they are transferred with the video data, it is difficult to know whether every end user receives it or not. In this situation, the video information was designed to transfer by RTCP Application-Defined (RTCP APP) packet. Video parameters information was added into RTCP APP packet and sent out to receivers. To ensure the successfully delivery of RTCP APP packet, RTCP APP packet is sent twice within certain time, T, that receivers start to use the new information of video parameters.

CONCLUSION

In this paper we provide a tutorial about video streaming over wireless mesh networks (WMNs). Wireless mesh networks because of their specifications such as self-organizing, self-managing and self-healing are considered as topology of next generation of wireless networks. WMNs are classified into three categories. Nodes in WMN are two types: clients and routers. For streaming video we may consider video characteristics such as image size, frame rate, pixel resolution and compression factor. Each of these parameters has a defined effect on video quality. In duration of streaming video may be affected by some impairment. These impairments cause lost packets, out-of-sequence packets and jitter. Several techniques are used for video streaming over wireless networks, such as path determination based, adaptive quality and cross layer information. Each of them has good and bad characteristics and a many open research areas in video streaming over wireless mesh networks are exist.

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