Design and Implementation of 400 MHz Video Real-Time Transmission System Based on Self-Organizing Wireless Mesh Network

Li Gao¹, Jiali Yang²*, Mingying Lan³ and Xupeng Ren⁴

¹ School of Digital Media and Design Arts, Beijing University of Posts and Telecommunications, Beijing 100876, China
² School of Information and Communication Engineering, Beijing University of Posts and Telecommunications, Beijing 100876, China
³ School of Digital Media and Design Arts, Beijing University of Posts and Telecommunications, Beijing 100876, China
⁴ Beijing ChangJiaoHe Technology Company, Beijing 100876, China

* Email: yangjiali@bupt.edu.cn

Abstract. At present, the common wireless multimedia transmission systems are mainly based on mobile networks and wireless local area networks. Most of the devices work in the 2.4 GHz/5 GHz frequency band and have poor signal penetration capability, which is not suitable for complex environment applications. Meanwhile, Wireless mesh networks are characterized by self-organization, self-healing, multi-hop and so on. In this paper, we down-converted the 2.4 GHz Wi-Fi signal, designed and implemented a wireless mesh network architecture broadband wireless multimedia transmission system based on the IEEE 802.11s protocol, which works at 400 MHz, the open band I. The system consists of a mobile central node station and 15 simple mobile stations to form a self-organized network, realizing independent wireless multimedia transmission in complex environment. According to results, its signal can diffract most objects in real scenes, such as 2-storey basement and 3-storey above ground buildings, which has high mobility, high reliability and meets complex wireless environment applications such as complex buildings, basements, jungles, etc.

1. Introduction

Aiming at the problems in the existing wireless multimedia transmission systems, we propose a multimedia transmission system scheme based on self-organizing wireless mesh network (SOWMN) working at 400 MHz. Compared with 2.4 GHz radio waves, 400 MHz radio waves have stronger penetration and diffraction capabilities, longer wavelengths and transmission distances under the same loss. The equipment in this band is infrequent so that the possibility of interference is less. Moreover, wireless mesh networks are flexible with high mobility, reliability, high stability, good network scalability and so on [1]. Principle of our wireless multimedia transmission system is shown in Figure 1.

Figure 1. Principle of the multimedia wireless video transmission system based on self-organizing wireless mesh network.
2. Path Loss Model of 400 MHz Radio Wave

Okumura model is a radio propagation model expressed by graphs through recording a large number of actual test data, also the most widely used model for propagation prediction in urban environment [2]. Hata model is an empirical formulation based on the data from the Okumura model, and it is valid for 150–1500 MHz microwave frequencies [3]. The standard formula for path loss of Hata model for urban environment is

\[ L_m(d) = 69.55 + 26.15 \log_10(f) - 13.82 \log_10(h_t) - a(h_t) + \left(44.9 - 6.55 \log_10(h_t)\right) \log_10(d) \]  

(1)

Where \( f \) is the carrier frequency (MHz), \( h_t \) is the transmitting antenna height (m), \( h_r \) is the receiving antenna height (m), \( d \) is the linear distance (km) between the transmitter and the receiver, and \( a(h_t) \) is the correction factor of receiver antenna height. For small or medium-sized city environment:

\[ a(h_t) = (1.1 \log_10(f) - 0.7) h_t - (1.56 \log_10(f) - 0.8) \]  

(2)

In large cities, \( a(h_t) \) when the carrier frequency is greater than 300 MHz is:

\[ a(h_t) = 3.2 \left( \log_{10}(11.75 h_t) \right)^2 - 4.97 \text{dB} \]  

(3)

However, the indoor propagation of radio waves will vary greatly according to the specific environment, since indoor path loss is affected by many factors, such as walls, tables and chairs, etc. Therefore, it is difficult to establish a general model for accurately calculating the path loss. A specific indoor model must be able to reflect the attenuation of signals by floors and partitions in a better way.

In logarithmic path loss model [4], for any distance between RF transmitter and receiver, the average path loss is

\[ L_m(d) = L_m(d_0) + 10n \log_{10} \left( \frac{d}{d_0} \right) \]  

(4)

Where \( d_0 \) is the near-ground reference distance, which is determined by the test, and the reference distance should be at the far field of the antenna. \( n \) is the path loss index, which is related to the specific propagation environment and depended on the surrounding environment and building type. The value of \( n \) is 2 when it’s in free space environment. \( d \) is the distance between the transmitter and receiver.

Keenan-Motley model considers the influence of walls and floors [5], and the path loss model is

\[ L_m(d) = L_m(d_0) + 20 \log_{10} \left( \frac{d}{d_0} \right) + \sum_{i=1}^{N_f} FAF_i + \sum_{j=1}^{N_p} PAF_j \]  

(5)

Where \( d_0 = 1 \text{m} \) is generally taken to denote near-ground reference distance, \( FAF_i \) is the attenuation value of radio waves passing through the \( i^{th} \) floor. \( PAF_j \) is the attenuation value passing through the \( j^{th} \) partition wall. \( N_f \) and \( N_p \) are the number of floor layer and partition layer, respectively. \( d \) is the distance between the RF transmitter and the RF receiver.

3. Design of the 400 MHz Wireless Multimedia Transmission System

3.1. Overall Architecture Design of the 400 MHz Wireless Multimedia Transmission System

SOWMN consists of a plurality of wireless mobile nodes, which rely on the nodes themselves to form the network, and distributed control algorithms to realize necessary functions of control and network.

There are two types of 400 MHz wireless multimedia nodes: basic nodes and central nodes. (1) basic one: information acquisition and transmission. (2) central one: receive, store, display and communicate with external networks. The architecture of the 400 MHz wireless multimedia
transmission system based on SOWMN is shown in Figure 2, in which there are 16 basic nodes and one central node. Any two adjacent nodes can be connected to each other equipped with relay forwarding function. The information sent by any node can reach the destination node directly or indirectly through the adjacent node.

Figure 2. Overall architecture of the 400 MHz wireless multimedia transmission system based on self-organizing wireless mesh network.

3.2. Design of the Radio Frequency Transceiver and Down-Conversion Radio Frequency module

The wireless transceiver comprises a radio frequency transmitting module and a radio frequency receiving module. For transmitting, the signal is modulated, up-converted, amplified and filtered. On the contrary, the radio frequency receiving module is used to receive signals, and filter and amplify them to obtain baseband signals after demodulation.

Figure 3. Structure of the wireless transceiver.

The system adopts AR9344 SoC developed by Atheros as the core of the down-conversion radio frequency module. The module consists of the chip AR9344 (generates 2.4 GHz basic signals), the reconfigurable frequency conversion chip RFFC2071, the peripheral filters, amplifiers and other devices, and its main function is to complete the conversion between 400 MHz RF signals and bit data. Compared with 12.5 cm, the 2.4-GHz radio wavelength, 400 MHz radio wavelength is 75 cm, which means its diffraction ability is better, and it can diffract most objects in real scenes, such as 2-storey basement and 3-storey above ground buildings. A mixer is used to down-convert signal, as shown in Figure 3-3.

Figure 4. Principle of radio frequency transceiver for wireless signals.

2.4 GHz signals are used for communication through down-conversion technology. Video data obtained from cameras is sent to the interface of AR9344, which transmits the received baseband signal to the radio frequency interface through internal bus, and then the received baseband signal is moved to 2.4 GHz. Next, this signal is down-converted by the mixer circuit from 2.4 GHz to 400 MHz, and send to power amplifier and antenna for transmission, as shown in Figure 4.
Figure 5. Schematic of up/down conversion principle.

4. System Joint Debugging and Testing

4.1. PCB Fabrication

We obtained the PCB board of radio frequency transceiver after professional RF PCB design, and its parameters are shown in Table 1 and Table 2.

Table 1. Frequency table of RF video transmission module.

| Channel bandwidth (MHz) | Central frequency (MHz) | Occupation frequency (MHz) |
|-------------------------|-------------------------|---------------------------|
|                         | 395                     | 392–397                   |
|                         | 400                     | 397–402                   |
|                         | 405                     | 402–407                   |
| 5                       | 395                     | 390–400                   |
|                         | 400                     | 395–405                   |
|                         | 405                     | 400–410                   |
| 10                      |                         |                           |
| 20                      |                         |                           |

Table 2. Parameters of the RF video transmission module.

| Modulation pattern       | QPSK/16-QAM/64-QAM |
|--------------------------|--------------------|
| Output power (dBm)       | Up to 30           |
| Receive sensitivity (dBm)| Up to −93          |
| Antenna type             | SMA                |
| Data rate (Mbps)         | 0.25–72            |

4.2. Implementation and Networking Test of the 400 MHz Multimedia Transmission System

A common mesh node is shown in Figure 6, in which a is the ERS400 wireless signal transceiver, b is the network camera, c is a large-capacity rechargeable battery, and d is an omnidirectional antenna adapted to a. For the practicability of mesh nodes, SMA antenna extension cord is used to lead the antenna interface out of the box, and a hole is made to facilitate video information collection. Both the wireless signal transceiver module and the camera are fixed on the aluminium-plastic plate with screws, and the battery is fixed with ties for convenient disassembly and replacement.
Internal/external picture of the central control mesh node is shown in Figure 7: a is ERS400 wireless signal transceiver, d is an omnidirectional antenna adapted to a, e is a video recorder, f is a large-capacity monitoring hard disk installed on part e, g is the extension interface of Ethernet port and headset, h is a roller mouse, i is the VGA video transmission line, and j is a monitor which is directly connected to the hard disk video recorder via VGA video line. As the multimedia data-receiving end, the central control mesh node is generally in a safe and stable position and is mainly powered by an external power supply.

4.3. Implementation of Multimedia Transmission Function

The wireless transceiver of this system works at 400 MHz. In the networking test, we set the IP of the wireless signal transceiver and the network camera on the same segment for connection, and set the transmission power (30 dBm), signal bandwidth (5 MHz), channel (397 MHz–402 MHz) and other parameters of the transceiver (code rate 2 Mbps, frame rate 25 f/s for camera). After the equipment was powered on, the two ordinary mesh nodes were successfully connected to the central mesh node. As the video transmission process shown in Figure 8, video captured by two ordinary mesh nodes was displayed on the central mesh node.

4.4. Function Test of the Multimedia Transmission System

The test for indoor complex environment adopted one central control node and three ordinary mesh nodes (respectively put in the complex building environment of test site shown in Figure 9). The mobile test was carried out in different scenes such as the 1st floor of basement garage, the 2nd floor of basement garage, easternmost side of the 1st floor and the 2nd basement and the 4th floor. All the
transmission occurred between nodes is non-line-of-sight. Results show that video can be received at the central mesh node in all the scenes.

![Figure 9. Map of the test site.](image)

In our outdoor test and outdoor mesh-networking test, the transmission environment and nodes location is shown relatively in Figure 10 and Figure 11.

![Figure 10. Environment of the transmission test with (a) 10MHz / (b) 5MHz bandwidth](image)

![Figure 11. Environment of the outdoor mesh network test with (a) 10MHz / (b) 5MHz bandwidth.](image)

Data obtained from the tests is shown in Table 3. In all test scenes, the building conditions are relatively complex (brick-concrete buildings with many obstacles), and all transmission worked well even in the extreme case of 3–6 brick-concrete walls. In the scene with an outdoor relay point, the design requirement of 200m transmission after mesh network can be completed by one hop.

**Table 3.** Table of application test of the wireless video transmission system.

| Test type | Bandwidth (MHz) | Condition            | Transmission distance (m) | Signal performance                                           |
|-----------|-----------------|----------------------|---------------------------|--------------------------------------------------------------|
| Indoor    | 10              | Complex buildings    | 30                        | Signal can reach from the 2nd basement to the 4th floor.     |
|           | 5               | Complex buildings    | 35                        |                                                              |
| Outdoor   | 10              | Brick building       | 80                        | Signal can penetrate 6 brick walls.                          |
|           | 5               | Brick building       | 100                       |                                                              |
| Mesh      | 10              | 1 Relay point        | 92+83                     | The transmission distance of signal is 200 m.                |
|           | 5               | 1 Relay point        | 100+100                   |                                                              |

Notably, the transmit power and antenna height are 30 DBm/W and 1.5 m respectively in all tests.
5. Concluding Remarks
This paper has completed the design and implementation of a broadband wireless radio frequency video transmission system based on SOWMN, and has carried out field tests under various environments. In the indoor complex environment test, point-to-point transmission can be completed between the 2nd basement and the 4th floor. In the mesh networking test, the line-of-sight video transmission and the non-line-of-sight video transmission both work well under the condition of one relay point outdoors. The system is stable and reliable and meets the actual needs.

6. References
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