Multi-channel access technology based on wavelength division multiplexing in wireless UV communication mesh network*

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In this paper, the multi-channel access technology of wavelength division multiplexing (WDM) in the wireless ultraviolet (UV) scattering communication is studied. A multi-interface and multi-channel device is deployed in each UV transceiver node. The band-pass filter is configured in the receiving node so as to realize the multi-channel access by use of the UV WDM technology. Both the UV communication node model and the UV channel model are established. Three types of UV no-line-of-sight (NLOS) multi-channel communications are simulated in the mesh topologies with NS2. The results show that the UV multi-channel access technology can increase network throughput effectively with using WDM.
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Ultraviolet (UV) region is usually defined as electromagnetic wavelength between 4 nm and 400 nm. The wavelength between 200 nm and 280 nm is referred to the solar blind region[1]. UV communication is able to implement non-line-of-sight (NLOS) links, and can also be employed in line-of-sight (LOS) links[2]. The scattering UV light by molecule, particles and aerosol in the atmosphere can carry large amounts of information between the source node and destination node. The UV communication system is suitable for both commercial and military applications. Usually, a UV communication system consists of three parts including UV transmitter, atmospheric channel and the receiver. The UV transmitter and receiver often use LED[3] and photomultiplier, respectively. A lot of researches have been done on UV channel model[4].

Combining the UV communication characteristics, the network communication is inevitable. The connectivity[5] and non-coplanar model[6] of wireless UV networks have been discussed. Also the routing algorithm of UV mesh network has been researched[7]. Node isolation probability for serial UV-C multi-hop networks[8] and neighbor discovery for UV ad hoc networks[9] were studied. However, these two methods researched communication between two nodes. If a node communicates with multiple nodes, we must adopt wavelength division multiplexing (WDM)[10] to realize communication. Considering the UV outdoor communication physics layer (PHY) properties, a medium access control (MAC) protocol is designed to exploit multi-fold spatial reuse opportunities with appropriate configurations[11]. In UV communication, how to allocate channel is a very important issue. So we use the MAC protocol to solve the UV channel allocation problem. The UV channel resources can be shared efficiently and reasonably for multi-user in UV communication network. In this paper, we design a multi-channel access protocol considering the features of UV communication. The WDM technology is used to achieve multi-channel access in the MAC layer. In order to improve the performance of the UV communication network, the multiple transceivers can be employed in each node.

Because of scattering caused by molecules and aerosols in the atmosphere, the UV light is attenuated rapidly[12]. UV radiation can cover the obstacle, realizing the NLOS communication.

There are three typical transmitter and receiver configurations, depending on the transmitter divergence angle and the receiver field of view (FOV), as shown in Fig.1.

When analyzing UV NLOS (a) communication model, the coverage of NLOS (a) is a circular area with the equal communication distance in each direction. But the radius of coverage of NLOS (a) is small, and the effective com-

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munication distance is limited. The communication performance is poor with narrow bandwidth, long delay and seriously distorted signal. The NLOS (c) communication mode mainly considers the forward scattering, but there is some backward scattering near the transmitter. In order to achieve better communication performance, the receiver must be in the forward scattering coverage. The end-to-end delay of UV NLOS (c) is lower, and the communication bandwidth is larger. But the coverage of UV NLOS (c) has strong directivity. The communication performance of NLOS (b) is between those of the NLOS (a) and NLOS (c) models.

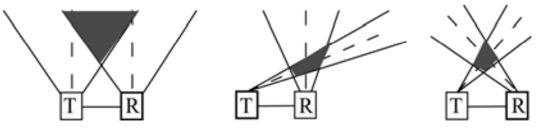


Fig.1 UV NLOS communication mode configurations[2]

A high-degree angle-independent scattering occurs when UV waves propagate in the atmosphere, creating communication path from source to destination. In order to improve the network performance, we have multiple interfaces configured for each node of the UV network, and each interface has one set of transceiver. The transceiver can adopt different wavelengths to transmit information. In addition, each transceiver has a certain direction coverage. The schematic diagram of UV multi-transceiver node is shown in Fig.2. Node A has three UV interfaces, which can communicate with nodes B, E and F, respectively. Node B has three UV interfaces, and it can communicate with nodes C, D and A, respectively. When the network topology is fixed, the network interface number of each node is fixed, and each interface corresponds to a fixed-wavelength channel.

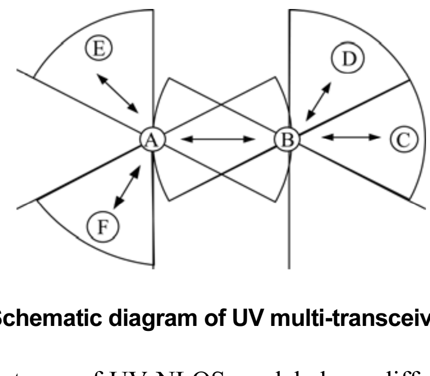


Fig.2 Schematic diagram of UV multi-transceiver node

Three types of UV NLOS models have different coverages in different directions, so the multi-channel UV model can combine space division multiplexing and WDM to improve the network performance. That is to say the communication nodes can be distributed different wavelengths of UV optical source in different directions[13]. Different signals are loaded on different wavelengths of UV light, and then the modulated signals propagate in the atmosphere by scattering. A band-pass filter is set at the receiver, and then the signals can be amplified by the detector. The original signals can be got after the signals are demodulated. We employ some narrow band interference filters with the center wavelengths of 214 nm, 228 nm, 253 nm and 266 nm, respectively, full width half maximum (FWHM) of 10 nm and the peak transmission of 20%. The transmittance diagram of blind UV filter is shown in Fig.3, which can realize the multi-channel UV communication based on wavelength division multiplexing.

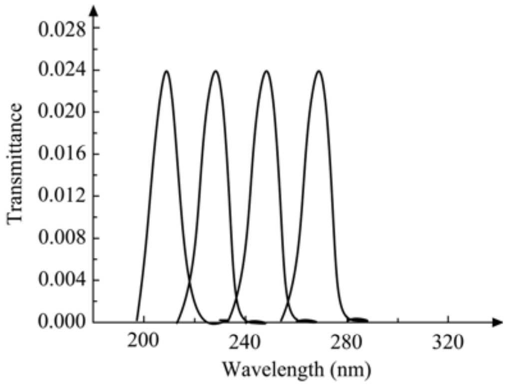


Fig.3 Transmittance diagram of the blind UV filter

The proposed UV multi-channel node model is shown in Fig.4. Through comparative analysis of radio communications and UV communication node model, the model components of the PHY and link layer are re-configured in the UV-node. Each interface of UV communication node configures a transceiver, which can choose different interfaces and channels to transmit the data packets according to the physical address. When the interfaces are used to transmit data packets, the link layer files need to be modified. The ARP module can parse out the interface number of data packets, and the data packets are transmitted to the corresponding queue with the interface number, then to the corresponding MAC layer, finally to channel through the corresponding network interface. The multi-interface ad hoc network communication has been simulated in Ref.[14]. In this paper, the multi-interface multi-channel communication model of UV communication is configured and implemented. The UV NLOS transmission model is established by adding UV NLOS communication model in the two-ray ground of NS2 with the link formula of the receiving optical power[15].

The UV-directional static routing protocol is mainly modified based on ad hoc ondemand distance vector (AODV). The protocol includes judging the channel is idle or not, exchanging request to send/clear to send (RTS/CTS) frame, and sending and receiving data packets.

The network nodes are in idle channel scanning mode before communication. Supposing that node 1 sends data to the node 2, the node 1 will determine whether the channel is idle. In the determination of the former, the node 1 must firstly detect the required UV light source directional network allocation vector (DNAV) value is zero or not corresponding to the DNAV table of node 2. If zero, the channel is idle, otherwise, the node returns to the initial idle channel scanning mode.

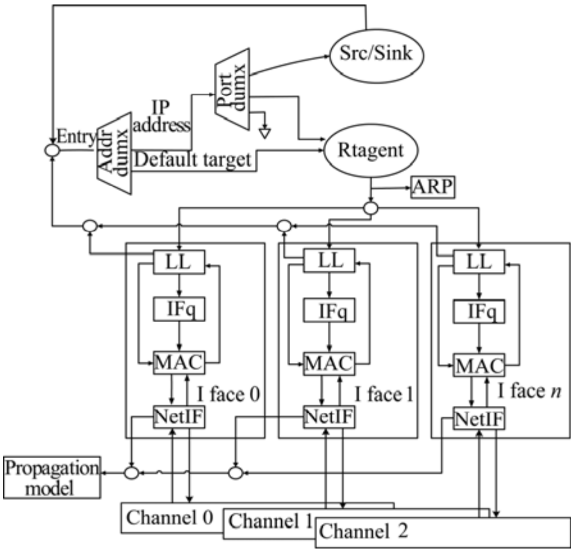
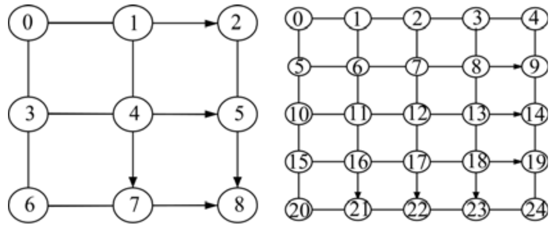


Fig.4 Model of UV multi-channel node

When the node 1 judges that the channel is idle, the node 1 will test whether the node 2 is in the interface neighbor table. If the node 2 is in the neighbor table of node 1 and the DNAV value is zero, all interfaces can be chosen and then the RTS is transmitted by the sending elevation angle. Otherwise, choose the interface whose DNAV is zero in DNAV table, and transmit RTS frame with the minimum elevation angle. The aim is to minimize the number of hops in the process of channel appointment (the exchange of RTS/CTS frame). Node 2 receives the RTS from node 1. If DNAV table values of the interface are zero, the interface will be chosen to transmit CTS by the relevant sending elevation angle. Once node 1 receives the CTS, the channel reservation is successful, and then the data is sent after waiting for short inter frame space (SIFS) time. Otherwise, the channel reservation is failure. And neighbors of node 1 and node 2 update the DNAV table according to the receiving RTS frame and CTS frame, respectively.

When node 1 and node 2 successfully exchange RTS/CTS, the channel can reserve successfully. The neighbor of node 1 selects the interface corresponding to the direction of the node 2 to send data. When node 2 receives the data from node 1, node 2 selects the interface with corresponding direction of node 1 to reply the acknowledge (ACK) frame. Once node 1 successfully receives the ACK frame, the data can be transmitted successfully.

In order to analyze the multi-channel multi-interface performance of UV NLOS communication, we do some simulations in NS2 software. In UV NLOS communication, the sending elevation angles and receiving elevation angles of three modes are set as (90°,90°) at NLOS (a), (30°,90°) at NLOS (b), and (20°,60°) at NLOS (c). The coverages of UV NLOS (b) and NLOS (c) are simplified as sector, the angle of sector coverage is set as 45°, and the communication distance between nodes is 200 m. There are three available channels, the data packet length is 1000 bytes, and the simulation time is 100 s. The 3×3 and 5×5 mesh topologies are shown in Fig.5.

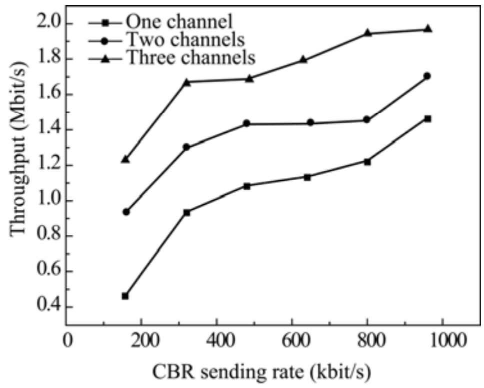


(a) 3×3 mesh topology (b) 5×5 mesh topology

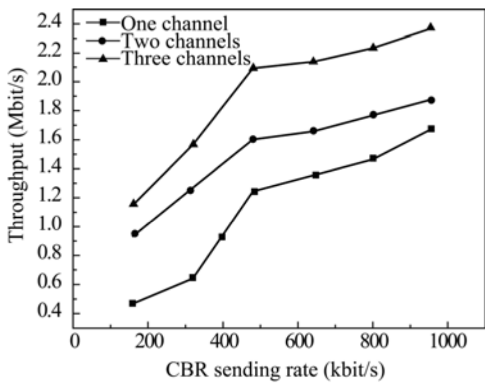
Fig.5 Two mesh topologies

The simulation results of NLOS (a), NLOS (b) and NLOS (c) are respectively shown in Figs.6 and 7. Through the comparative analyses, it can be seen that the throughput of UV NLOS (c) is the maximum. It is because directional communication can increase the spatial multiplexing rate. In UV NLOS (c) communication, the spatial multiplexing rate increases greatly, so the impact of deafness issues on the network can be alleviated. And the performance of UV NLOS (b) is between those of NLOS (a) and NLOS (c).

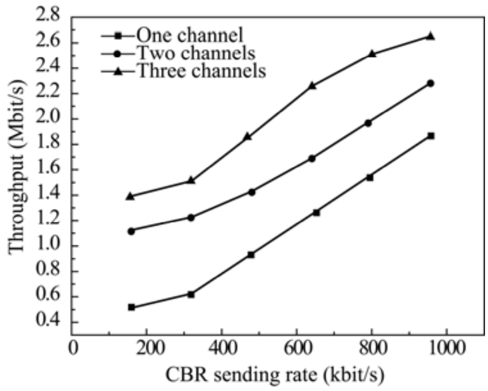
It can be seen from Figs.6 and 7 that the throughput capacity of single-channel communication is the lowest no matter with what kind of communication mode. In the dual-channel and the three-channel communications, the throughputs of three modes of UV NLOS communication are significantly increased. The throughput curve of NLOS (a) communication is relatively stable, and the network throughput is obviously rising with the channel number increasing. In NLOS (b) communication mode, the network throughput is rapidly raised with the channel number increasing, but it has a certain decline when the network is under a heavy load. In NLOS (c) communication, the throughput curves of dual-channel and three-channel communications are sharply raised, and the throughputs have a slight decline when the network has a heavy load.



(a) NLOS (a)

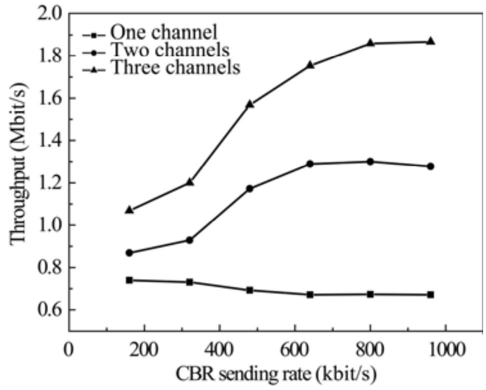


(b) NLOS (b)

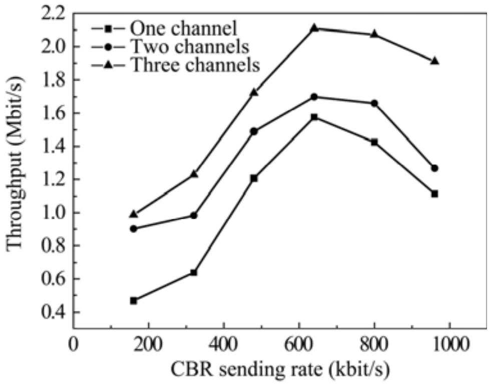


(c) NLOS (c)

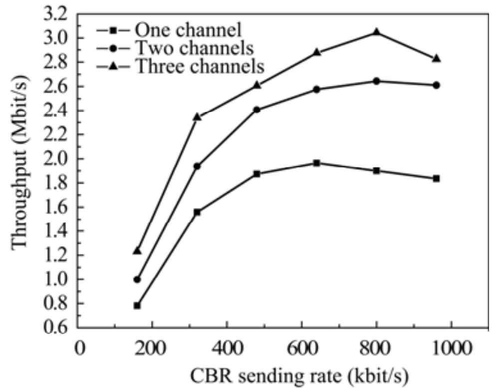
Fig.6 Throughput of 3×3 mesh topology



(a) NLOS (a)



(b) NLOS (b)



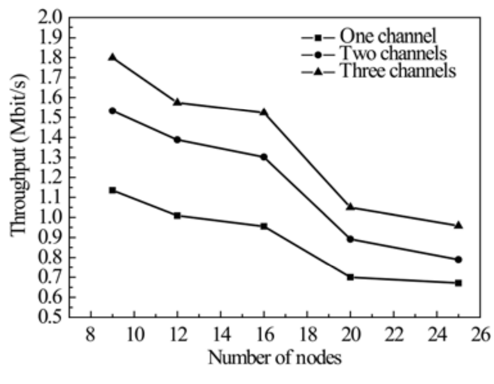
(c) NLOS (c)

Fig.7 Throughput of 5×5 mesh topology

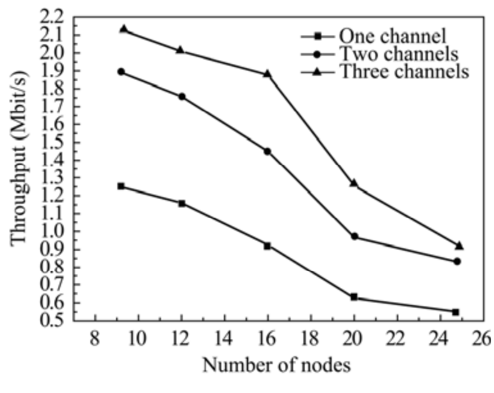
The simulation results also show that the network throughput increases with the number of channels increasing and decreases with the number of nodes increasing. The more communication nodes, the worse the multi-channel performance will be. Simultaneously, the network throughput is gradually decreased.

In the same initial conditions, there are three available channels, the data packet length is 1000 bytes, the data transfer rate is 640 kbit/s, and the simulation time is 100 s. The simulation results of different topologies with varying number of nodes are shown in Fig.8.

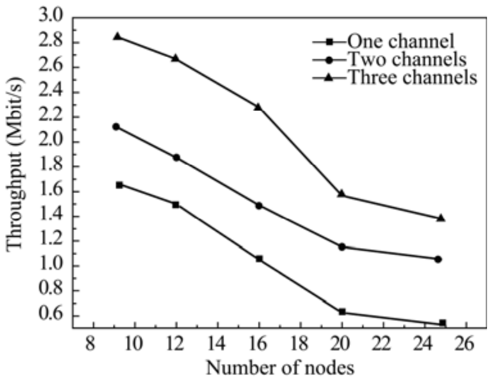
In Fig.8, the throughput of NLOS (c) network is the largest, followed by that of the NLOS (b) communication, and throughput of NLOS (a) is the minimum. The



(a) NLOS (a)



(b) NLOS (b)



(c) NLOS (c)

Fig.8 Throughput of varying nodes

network throughput decreases with the number of nodes increasing. The more nodes, the smaller the advantage of the multi-channel is, and the network throughput is also decreased. The interval of throughput curve is uneven in the simulation diagram, but the performance of NLOS (c) is better. This is because in the multi-hop communication, contention channel between two nodes occurs, and then there will be interference, which affects the network throughput, so the simulation curve interval is not uniform.

The UV NLOS multi-channel communication model is presented in this paper. In order to improve the UV network performance, we establish the UV communication system model based on WDM. The original NS2 node model is extended, and the implementation procedure of UV-node model is described. The UV NLOS directional channel access protocol is also introduced in detail. The UV multi-channel is simulated in mesh topology. The throughput of NLOS (a) is relatively small, but the curve is more stable. Because NLOS (c) communication is omni-directional transmission and omnidirectional reception, it can improve the spatial multiplexing rate. The throughput of NLOS (c) is the maximum among the three types of UV NLOS communications. NLOS (b) adopts directional transmission and omnidirectional reception, whose performance is between those of NLOS (a) and NLOS(c). The network throughput is increased with the number of channels increasing. With the number of the network nodes increasing, the network throughput decreases, and the multi-channel performance declines. Meanwhile, the intervals of the simulation curves are not uniform.

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