# SDM Technology based on Spot-beam Antenna

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**Abstract.** In Time Division Multiplexing system, the central station broadcasts data packets to the subscriber station, and the proportion of valid data packets received by each subscriber station gradually decreases as the number of subscriber stations increases. The use of space resources can improve the time efficiency of time-division systems. Based on time-division, this paper proposes a space-time channel segmentation method by using spot beam antennas to introduce spatial resources. According to the time-space segmentation method, a Space Division Multiplexing technology based on spot beam antenna is proposed. In the case of the Additive White Gaussian Noise channel, it was verified by simulation that the Space Division Multiplexing technology can effectively improve the channel capacity.

**Keywords:** Space Division Multiplexing; Time Division Multiplexing; Spot Beam Antenna; System Capacity.

## 1. Introduction

TDM (Time division multiplexing) is a commonly used multiplexing method. The central station broadcasts data packets to all subscriber stations in the area, and the subscriber station obtains the required data packets from all the received data packets. In this process, the subscriber station receives both its own data packet and the data packets of other subscriber stations. For a subscriber station, the data packets of other subscriber stations are waste packets, and the transmission of these data packets occupies bandwidth, but has no effect. This leads to a low TMD downlink bandwidth utilization. And as the number of subscriber stations increases, the proportion of subscriber stations receiving waste packets is increasing, and the bandwidth utilization rate is further reduced.

Spot beam antennas have received more and more attention in the field of wireless communication because of its high gain, strong directivity, and frequency multiplexing. SDM (Space Division Multiplexing) based on spot beam antenna has also achieved some results, such as 5G core technology massive MIMO (multiple-input multiple-output) technology [1][2][3], frequency reuse in satellite communication [4][5][6], and one station multi-machine in the UAV (Unmanned Aerial Vehicle) data link [7][8][9].

In the second section of this paper, based on the time division user of TDM, the space resources were increased by using the spot beam antenna, and a time-space division channel was proposed. According to the theory, using the spot beam antenna to quickly adjust the pointing technology, an SDM communication technology based on point beam pointing and packet-by-packet adjustment was proposed. In the third section of this paper, in the case of the channel being AWGN channel, the simulation analysis showed that the technology can effectively improve the frequency band utilization.

## 2. Introduction to SDM System

### 2.1 Time-Division and Space-Division Theory based on Spot-beam Antenna

Assumption 1. The communication scenario is a central station to downlink communication for N subscriber stations.

Assumption 2. The service statistics of each subscriber station are the same.

Assumption 3. The downlink channel rate is R, and the occupied frequency bandwidth is W.

Assumption 4. The data packet is a fixed length packet and has a duration of T.

Remark 1. The unit time is NT.

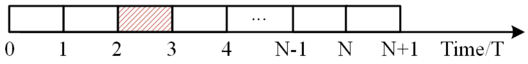



Fig. 1 TDM Time Slot Allocation

In the TDM system, the central station broadcasts data packets to all subscriber stations. As shown in Fig. 1, each subscriber station receives an average of one packet per unit time, so the average rate received by each subscriber station is:

$$R_{TDM}=R/N \tag{1}$$

In the SDM system, the central station uses a spot beam antenna, and multiple transmitters can be used to form m spot beams that can quickly switch directions. Under reasonable scheduling, different transmitters can simultaneously transmit signals of the same frequency bandwidth without interference with each other using different beams, as shown in Fig. 2. When the central station has a data packet to be sent to a small station, select the idle antenna, adjust the beam pointing, and send to the corresponding subscriber station.

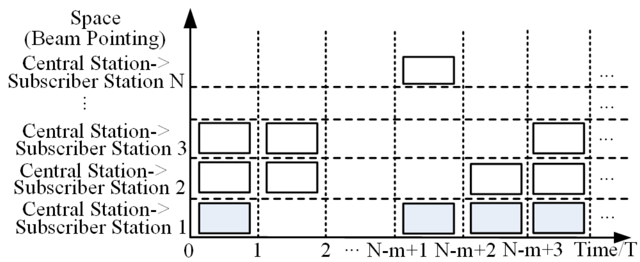



Fig. 2 Time Space Allocation

Then each user station receives an average of m data packets per unit time, so the average rate received by each user is:

$$R_{mSDM}=mR/N \tag{2}$$

That is, in the SDM system, the central station increases the downlink rate to m times the TDM within the same bandwidth, by using m spot beams and utilizing the characteristics that the beam space does not interfere with each other. In the SDM system, in order to take advantage of the application environment of the time division system, generally $m \leq N$.

## 2.2 SDM Technology based on Spot-beam Antenna

According to the theoretical basis of the previous section, the SDM system consists of a central station and a number of subscriber stations equipped with several transmitters of identical performance, each connected to a point-beam antenna that can be quickly adjusted.

The working mode of SDM: Before the data packet is sent, the central station adjusts the beam pointing in real time according to the geographic location of the corresponding user station of the data packet, and adjusts the beam to the direction of the user station accurately and quickly, and sends the data packet. The flow chart of downlink data transmission from the central station to the subscriber station is shown in Fig. 3.

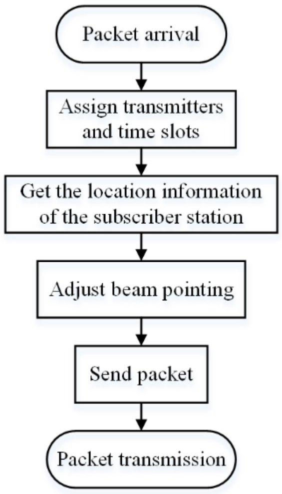



Fig. 3 Flow chart of data transmission by the central station

All workstations (including central stations and subscriber stations) use location devices to obtain their location information in real time. When the system is initialized or the subscriber station moves, the central station can obtain the geographical location information of the subscriber station in time, and establish a geographic location information table of the subscriber station. The central station can calculate the beam pointing table according to the geographical location table of the user station and its geographical location information.

The central station uses a spot beam antenna to communicate with the subscriber station. Each beam of the spot beam antenna is narrow and covers just as a subscriber station. Moreover, the beam pointing direction of the antenna is fast, and the beam adjustment can be pointed to the subscriber station accurately. Some phased array antennas can satisfy the above conditions.

The central station transmits data packets to the subscriber station in burst mode, and all transmitter time slots are strictly aligned.

## 3. Simulation Analysis

### 3.1 Simulation Parameter Setting

In the simulated scenario, the channel is an AWGN channel, and the beam of the central station cannot cover two subscriber stations at the same time, and the center frequency, bandwidth, and modulation mode of all the transmitters of the central station are exactly the same. For example, a scenario in which a relay drone of a medium-distance line-of-sight communication communicates with a ground station using a phased array antenna meets the above conditions. As shown in Fig. 4, in this scenario, the central station is a UAV (Unmanned Aerial Vehicle) relay platform, the subscriber station is a ground station, and the link from the central station to the subscriber station is a downlink.

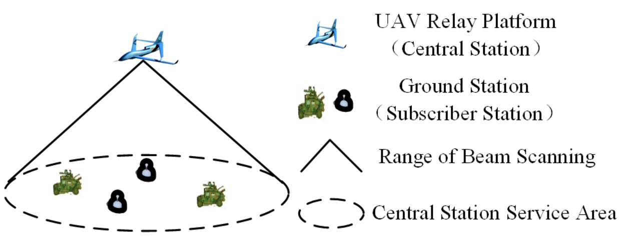
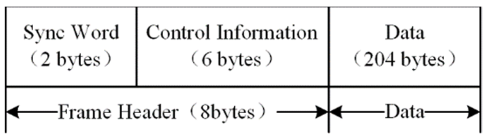


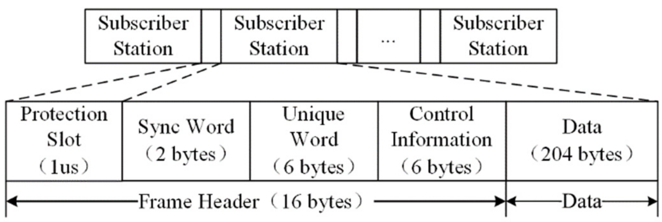

Fig. 4 Simulation scene

The flying height of the central station is H, the number of beams of the phased array antenna used for communication between the central station and the subscriber station is m, the scanning range of the beam is θ, the beam width is ω, and the number of subscriber stations in the coverage is N. In order to ensure that one beam cannot cover two subscriber stations, the distance between any two subscriber stations is limited to be greater than $\omega H/\cos^2(\theta/2)$. In the downlink, the communication bandwidth is W, the modulation mode is QPSK, and the channel rate is R.

The UAV relay belongs to the long-distance line-of-sight communication. The DVB-S2 (The second-generation Digital Video Broadcasting by Satellite) standard can be used to package the data packets (as shown in Fig. 5): (1) TDM uses broadcast mode, and the broadcast packet consists of an 8-byte header and 204 bytes of data. The frame header of the broadcast frame consists of a 2-byte sync word (holding carrier synchronization and bit synchronization) and 6-byte control information (for signaling transmission). (2) The burst mode is used in the SDM downlink, and the burst frame is composed of a 16-byte frame header and 204 bytes of data. The frame header of the burst frame consists of a 2-byte sync word (guaranteed synchronization between the central station and the subscriber station), an 8-byte unique word (flags the start of a new frame), and 6-byte control information (transmission control information). Due to the geographical difference of each subscriber station, it is also necessary to set a protection slot of 1 microsecond.




Frame structure of TDM broadcast frame




Frame structure of SDM burst frame

Fig. 5 Frame Structure of the Downlink Data Frame

The arrival of the downlink data packet is bursty, assuming that the arrival process of the data packet is a Poisson process.

The central station uses the following methods for scheduling packets:

(1) TDM is a broadcast method, and a scheduling method of FCFS (First Come First Served) is used.

(2) SDM expands the FCFS mode by using as many beams as possible at the same time: After the data packet is sent, the data packets of the first m destinations that are first arrived are selected from the waiting queue for transmission.

In order to increase the channel usage, the data packet needs to set a maximum timeout in the central station. When the data packet of the central station times out, the central station discards the data packet. This phenomenon is called packet loss. And the subsequent packet loss only considers the packet loss caused by the timeout. The probability of packet loss is the packet loss rate. The packet loss rate directly measures the communication status of the link. Considering the demand for voice services, set the maximum timeout period to 30ms.

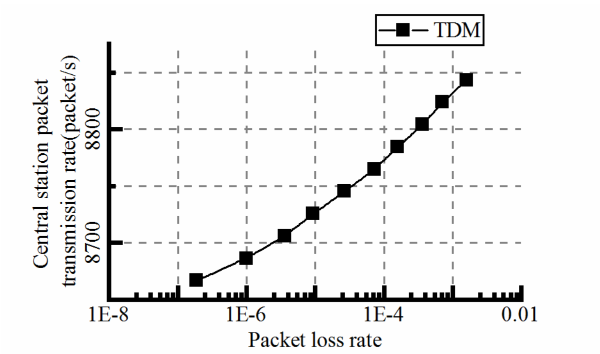
Then all the scene setting parameters are as shown in Table 1:

Table 1. Simulation Scene Parameter Settings

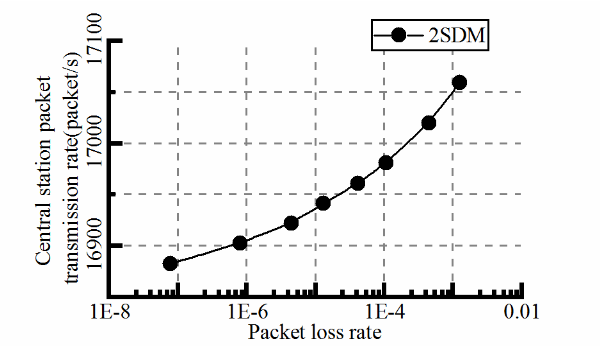
| **Environmental parameters** | **Values** |
|---|---|
| UAV flight altitude (H) | 10000m |
| Beam scanning range (θ) | 120° |
| Beamwidth (ω) | 3° |
| Number of subscriber stations (N) | 32 |
| Bandwidth (W) | 15Mhz |
| Downlink channel rate (R) | 15Mbps |
| Modulation | QPSK |
| TDM packet scheduling mode | FCFS |
| SDM packet scheduling mode | Extended FCFS |
| Number of beams in SDM (m) | 2-4 |
| Arrival process of the data packet | Poisson Process |
| Maximum timeout period | 30ms |

### 3.2 Simulation Results

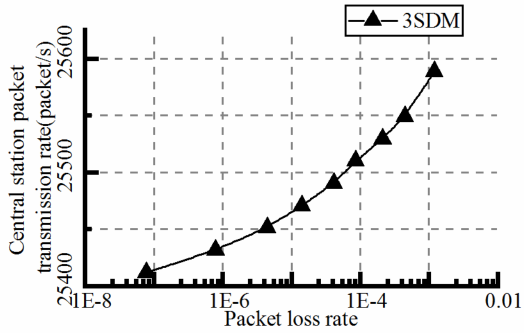
According to the scenario in Table 1, use MATLAB for simulation analysis: gradually increase the rate at which the central station transmits data packets to the subscriber station, and count the packet loss rate corresponding to the rate at which the central station transmits the data packet. The simulation results are shown in Fig. 6 (mSDM in the illustration represents an SDM system with m beams).



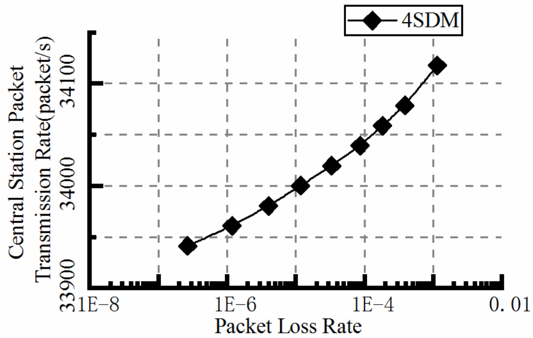

(a)




(b)




(c)




(d)

Fig. 6 Simulation Results of Packet Loss Rate - the Rate of the Central Station Packet

In the case of a given maximum timeout, the channel capacity of the central station is defined as: the maximum packet rate that the central station can transmit, which satisfies the packet loss rate limit. The packet loss rate of the communication system should be between $10^{-6}$ and $10^{-5}$. The case of the boundary is discussed here, that is, the timeout packet loss is limited to $10^{-6}$ and $10^{-5}$. According to the simulation results in Fig. 6, the second-fitting can be used to obtain the channel capacity of the central station with packet loss rates of $10^{-6}$ and $10^{-5}$ in different multiplexing modes, as shown in Table 2:

Table 2. Table Channel Capacity

| **Packet loss rate** | **Channel capacity (packet/s)** | | | |
|---|---|---|---|---|
| | ***TDM*** | ***2SDM*** | ***3SDM*** | ***4SDM*** |
| $10^{-6}$ | 8687.2 | 16901.3 | 25434.0 | 33957.8 |
| $10^{-5}$ | 8725.1 | 16933.7 | 25463.1 | 33994.6 |

As can be seen from Table 2, the capacity of the central station of SDM is significantly higher than that of TDM: for each additional spot beam of the SDM central station, the increment of the downlink channel capacity is approximately equal to the channel capacity of the TDM. Since the statistical characteristics of all subscriber station services are the same, the rate received by the subscriber station is equal to the capacity of the primary station divided by the number of subscriber stations. Therefore, the rate at which the subscriber station receives the data packet is the same as that of the central station.

## 4. Conclusion

In this paper, based on the theory of time-space segmentation channel, an SDM technique based on point beam pointing fast adjustment is proposed. In the case of the Additive White Gaussian Noise channel, it was verified by simulation that the Space Division Multiplexing technology can effectively improve the channel capacity. However, the scenario studied in this paper is relatively simple: the channel is an AWGN channel, the traffic statistics of all user stations are the same, the geolocation table is updated fast enough, and the beam is narrow enough. More complex scenarios require further research.

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