Research on Key Technologies of New Generation Vehicle Wireless Network

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Abstract With the continuous improvement of automobile intelligence, the delay, synchronization, reliability, security and concurrency of on-board network are required to be higher. In this paper, the key technologies of the new generation of vehicle-mounted wireless network are studied. According to the characteristics of in-vehicle data communication of intelligent vehicles, the network architecture, basic characteristics of physical layer, synchronization and access, resource allocation, channel coding and modulation are deeply studied and designed.

1 Introduction

As the last link of information transmission, wireless short-range communication technology plays a huge role in all aspects of social life. Every year, more than 10 billion new wireless short-range connected devices are put into the market, accelerating the birth of a large number of new applications and value scenarios [1]. With the development of applications, the emergence of new services puts forward new requirements for the existing wireless short-range communication technology in low delay, high reliability, precise synchronization, high concurrency and information security [2]. In particular, the automotive industry is in urgent need of wireless short distance communication technology that can better match the business demand and development trend. Based on this background, this paper designs a new generation of

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vehicle-mounted wireless network, aiming to promote the application of new wireless short-range communication technology including this technology in scenarios such as intelligent vehicles, and further promote the continuous evolution of new wireless short-range communication technology.

With the continuous improvement of automobile intelligence level, the requirements of in-car data communication are getting higher and higher [3–5]. At present, CAN (Controller Area Network) bus used by large commercial vehicles CAN not meet the current requirements in bandwidth, delay, concurrency and other aspects. Secondly, this paper studies a new generation of vehicle-mounted wireless network for the use of intelligent vehicles to meet new application requirements.

2 System Architecture

2.1 Network Architecture

Nodes in the system are classified into management nodes (G nodes) and managed nodes (T nodes). In specific application scenarios, a single G node manages a certain number of T nodes, and G nodes are connected to these T nodes to complete specific communication functions. A single G node and its connected T node together constitute a communication domain.

At this point, the CDC (Cockpit Domain Controller) and the vehicle-mounted device form a communication domain. When the mobile phone is connected to the CDC, the mobile phone can also serve as the T node in the communication domain. See Fig. 1.

In some scenarios, there may be multiple communication domains: In the environment of smart vehicles, mobile phones can also be used as G nodes to connect to wearable devices. At this point, mobile phones and wearable devices form

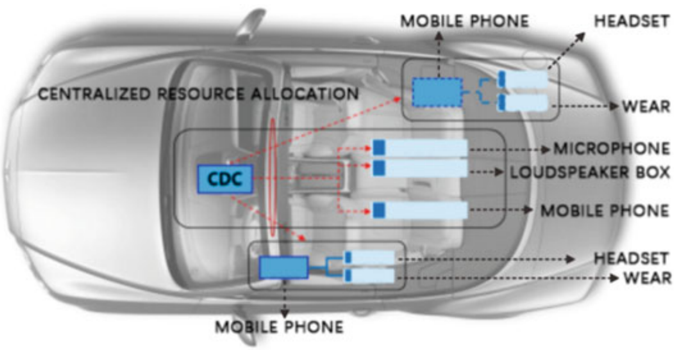


Fig. 1 Intelligent vehicle application

another communication domain. In the smart home scenario, the TV and the down-hanging audio device form one communication domain, and the mobile phone and earphone form another. The two communication domains can be distinguished by the advanced/common communication domain, and the advanced communication domain coordinates resources to achieve coordination and coexistence between multiple domains.

2.2 Protocol Stack Architecture

The system protocol stack is divided into application layer (OSI 5–7 layer), network and transport layer (OSI 3–4 layer) and access layer (OSI 1–2 layer), as shown in Fig. 2.

The data link layer ensures reliable data transmission. The data link layer consists of the link control layer and the media access layer. The link control layer mainly realizes transmission mode control, encryption and decryption, etc. The media access layer mainly realizes resource scheduling, data encapsulation, and transmission format control to meet QoS requirements of different services. The physical layer realizes the bit stream transmission function. The access layer also implements information security and management functions, which are used to ensure the security of the protocol stack and manage the communication. As shown in Fig. 3, in the process of data encapsulation, packet headers are added layer by layer at the data sending end. At the data receiving end, the data is unpacked in reverse order.

The system supports cross-layer transparent transmission for ultra-low latency periodic packet data transmission (such as audio transmission in active noise reduction services). This mechanism can determine the corresponding service parameters

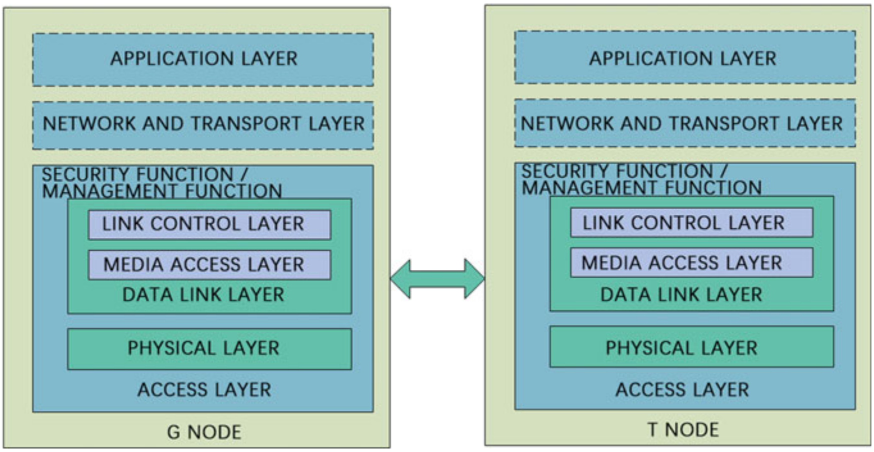


Fig. 2 System protocol stack architecture

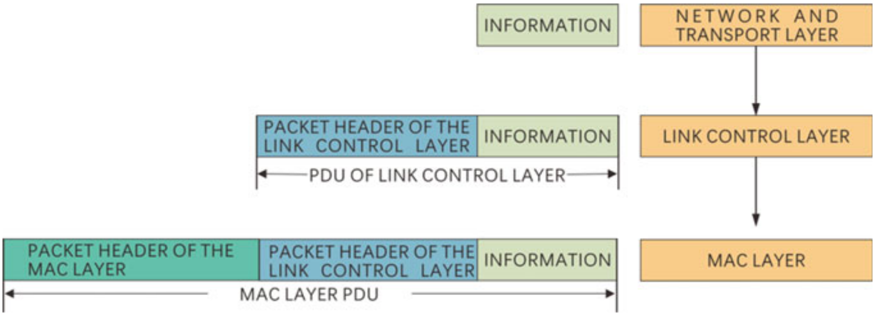
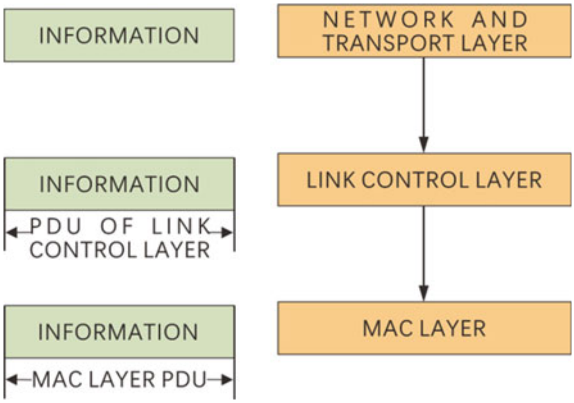


Fig. 3 System co-data encapsulation process

Fig. 4 System transparent transmission mechanism across layers



and the corresponding transport channel when the connection is established without adding the corresponding packet header at each protocol layer. This mechanism can reduce the overhead brought by the packet header, improve the transmission efficiency, and reduce the processing time of each layer to achieve the purpose of ultra-low delay transmission. See Fig. 4.

3 Physical Layer Base Properties

3.1 Transmission Waveform

The system adopts CP-OFDM (Cyclic Prefix-Orthogonal Frequency Division Multiplexing) waveform transmission, the physical layer time measurement is a multiple of the basic time unit T_s, T_s is defined as $T_s = 1/fs$, $FS = 30.72$ MHz, sub-carrier interval $\Delta f = 480$ kHz.

CP-OFDM symbol contains cyclic prefix part and valid data in the time domain. The length of the valid data part is $64T_s$, and the cyclic prefix length includes two types:

$$T_{\mathrm{CP}} = \begin{cases} 5 \times T_s, \text{Regular loop prefix} \\ 14 \times T_s, \text{Extended loop prefix} \end{cases} \tag{1}$$

CP-OFDM symbol time length (including the loop prefix):

$$\mathrm{T}_{\mathrm{Symb}} = \begin{cases} 69 \times T_s, \text{Regular loop prefix} \\ 78 \times T_s, \text{Extended loop prefix} \end{cases} \tag{2}$$

3.2 Channel and Subcarrier Design

The minimum carrier bandwidth of the system is 20 MHz, and the carrier bandwidth of 40/60/80/100/160/320 MHz is supported. The carrier bandwidth is composed of consecutive 20 MHz carriers. The carrier of 20 MHz is composed of 39 consecutive sub-carriers, with an interval of 480 kHz, numbered as #0,#1,… from the lowest frequency to the highest frequency.,#38, where the subcarrier #19 is the DC subcarrier and does not carry information. In a 20 MHz working bandwidth, the lowest frequency and the reserved part of the highest frequency resources do not place available subcarriers. See Fig. 5.

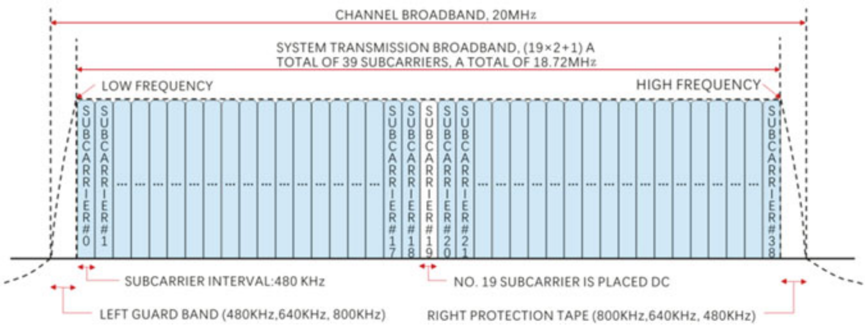


Fig. 5 System subcarrier division (20 MHz carrier)

3.3 Superframe Structure and Wireless Frame Structure

The system adopts TDD (Time Division Duplexing) mode, and the format of super frame is shown in Fig. 6 below. Each super frame contains 48 wireless frames, and the duration of each super frame is 1 ms, and the duration of each wireless frame is 20.833 µs. Where G symbol represents the symbol that G node sends to T node (G link), T node represents the symbol that T node sends to G node (T link), SG/ST respectively represents the symbol resource that can be used for overhead symbol in G/T symbol, and the overhead symbol resource of each wireless frame can be flexibly configured as 0, 1 or 2 symbols. GAP is the switching interval between G link symbol and T link symbol.

When using the conventional cyclic prefix, the wireless frame supports 14 G symbol T symbol ratio. When using extended loop prefix, wireless frame supports 12 G symbol T symbol ratio. Flexible G/T ratio can meet the requirements of service rates in different link directions in different application scenarios.As shown in Tables 1 and 2 below.

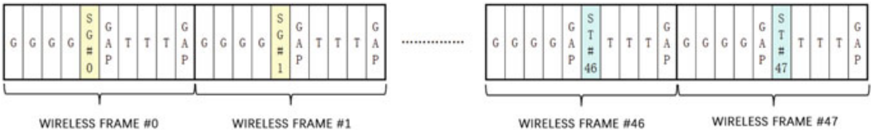


Fig. 6 System superframe structure

Table 1 Wireless frame ratio based on conventional cyclic prefix configuration

Wireless frame ratio	Symbol configuration							
	0	1	2	3	4	5	6	7
0	G	T	T	T	T	T	T	T
1	G	G	T	T	T	T	T	T
2	G	G	G	T	T	T	T	T
3	G	G	G	G	T	T	T	T
4	G	G	G	G	G	T	T	T
5	G	G	G	G	G	G	T	T
6	G	G	G	G	G	G	G	T
7	T	G	G	G	G	G	G	G
8	T	T	G	G	G	G	G	G
9	T	T	T	G	G	G	G	G
10	T	T	T	T	G	G	G	G
11	T	T	T	T	T	G	G	G
12	T	T	T	T	T	T	G	G
13	T	T	T	T	T	T	T	G

Table 2 Wireless frame ratio based on extended cyclic prefix configuration

Wireless frame ratio	Symbol configuration						
	0	1	2	3	4	5	6
0	G	T	T	T	T	T	T
1	G	G	T	T	T	T	T
2	G	G	G	T	T	T	T
3	G	G	G	G	T	T	T
4	G	G	G	G	G	T	T
5	G	G	G	G	G	G	T
6	T	G	G	G	G	G	G
7	T	T	G	G	G	G	G
8	T	T	T	G	G	G	G
9	T	T	T	T	G	G	G
10	T	T	T	T	T	G	G
11	T	T	T	T	T	T	G

4 Synchronization and Access

4.1 System Synchronization

The system is configured with two synchronization signals, FTS (first training signal) and STS (second training signal), which are placed in two adjacent wireless frames and sent in a cycle of superframes. ZC sequence is selected as the synchronization sequence. Compared with m sequencecommonly used as synchronization signal, ZC sequence has higher autocorrelation peak value, lower cross-correlation value and better anti-frequency offset performance, which is beneficial to improve the probability of synchronization success.

The FTS sequence function is:

$$d_{\mathrm{FTS}}(n)=\begin{cases}\exp\left(-j\frac{\pi un(n+1)}{41}\right), & n=0,1,\ldots,18\\ 0, & n=19\\ \exp\left(-j\frac{\pi un(n+1)}{41}\right), & n=20,21,\ldots,38\end{cases} \tag{3}$$

where, $u = 1$ for advanced communication domain and $u = 40$ for general communication domain.

The STS sequence function is:

$$d_{STS}(n) = \begin{cases} \exp\left(-j\frac{\pi u \frac{n}{2}\left(\frac{n}{2}+1\right)}{21}\right), & n = 0, 2, \ldots, 38 \\ 0, & n = 1, 3, \ldots 37 \end{cases} \quad (4)$$

Among them, $u = 1, 2, \ldots 20$ indicates the synchronization identifier of the communication domain. The STS sequence increases power by 3 dB when mapped to a subcarrier.

4.2 System Access and High Concurrent Transmission

High concurrency transmission mainly includes multi-node concurrency and multi-service concurrency. As shown in Fig. 7, multi-node concurrency means that a single G node can connect to multiple T nodes at the same time and provide services for multiple T nodes at the same time. Multi-service concurrency means that multiple types of services can coexist on a single T node to provide rich service experience for drivers.

To support high concurrency, the main technical points are as follows:

- Stable connection of a large number of users: In the system, the physical layer ID used to identify T nodes is 12 bits long. Theoretically, a SINGLE G node can support a maximum of 212 = 4096 T nodes.
- Access control mode: The system uses centralized scheduling to avoid link conflicts caused by preemption of distributed resources on a large number of nodes and improve system throughput. The system also supports non-competing access mode. A large number of T nodes can initiate group access from mutually orthogonal resources at the same time, achieving millisecond access and meeting service requirements in power-on and work-on scenarios.
- Intelligent scheduling based on service features: The system allows T nodes to report necessary service features to G nodes for intelligent scheduling. As shown in Fig. 8, for active denoising service, G node supports T node to report sampling

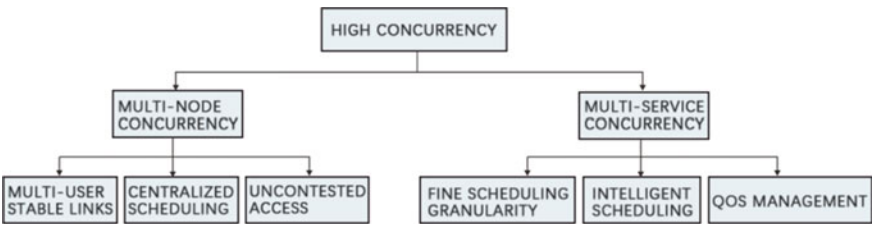


Fig. 7 High concurrency key technology

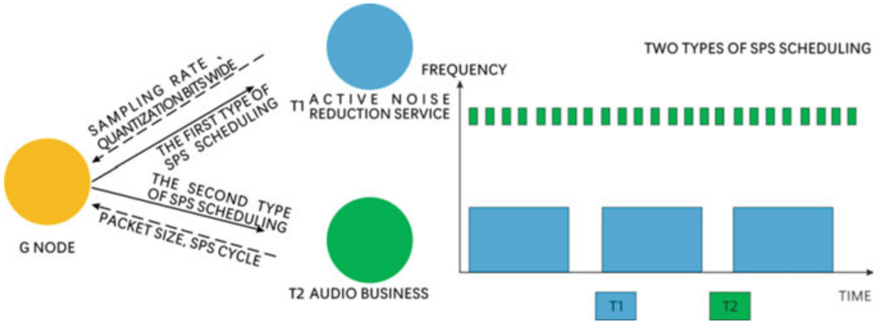


Fig. 8 System fine scheduling granularity and service intelligent scheduling

rate and quantization bit width. For semi-static scheduling services, T node can report the semi-static scheduling period and packet size to G node, facilitating G node to flexibly schedule services. In terms of scheduling, the system supports the logical channel priority mechanism to encapsulate data according to the logical channel priority. At the same time, the system can properly restrict the amount of data encapsulation of services with different priorities, and take into account the fairness of scheduling services with different priorities.

5 Resource Allocation

5.1 Resource Allocation in the Frequency Domain

The system supports ultra-low latency data transmission, also known as type 1 data transmission, and large packet/high traffic information, also known as type 2 data transmission.

Type 1 data transmission supports services with very low latency requirements. This type of data transmission requires high transmission reliability without retransmission. According to the transmission, system support minimum 1 is the carrier of scheduling granularity, G nodes according to the users in different channel fading of the subcarrier on (same subcarrier, different users to the corresponding frequency domain decline coefficient), scheduling of different sub-carrier data transmission, realize the combination of sub carrier scheduling, to the greatest extent promote each user and the system performance. As shown in Fig. 9 below, a single user is taken as an example to schedule the subcarrier with optimal channel conditions to transmit data.

For the second type of data transmission, the system supports scheduling granularity with 4 or 3 subcarriers as a group, so as to obtain sufficient frequency domain scheduling gain while reducing signaling indication overhead.

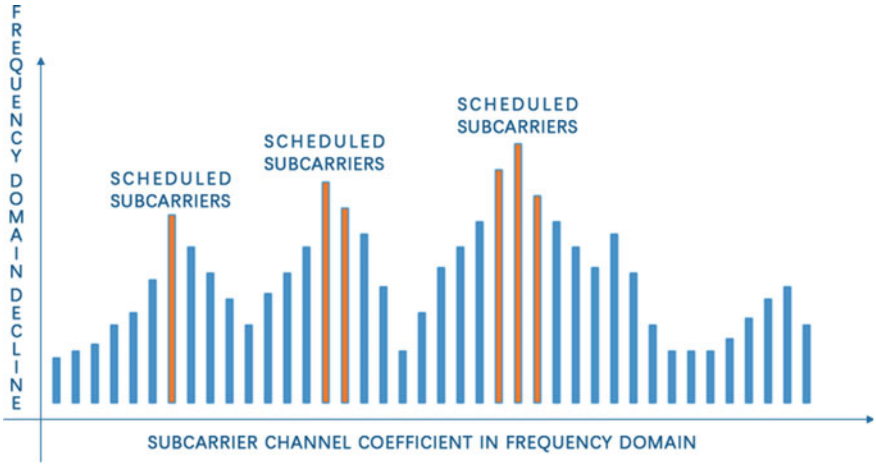


Fig. 9 Schematic diagram of decentralized scheduling principle

For system overhead signals, such as T-link ACK feedback signals and T-node access information, the system supports frequency resource comb transmission and the frequency resources used in information transmission are distributed within the entire bandwidth of a carrier to ensure the maximum frequency diversity of information transmission.

5.2 Time Domain Resource Allocation

With 20.833 μs wireless frame as the scheduling unit, the system supports flexible resource allocation in the time domain to meet the delay requirements of different application scenarios. The following key technologies are used to allocate time domain resources in the system:

- Short wireless frame: The length of each wireless frame is 20.833 μs. Because G link and T link can be configured for wireless frame transmission at the same time, the one-way transmission delay at the physical layer is no longer than 20.833 μs. The following Fig. 10 schematically analyzes two scenarios in the case of semi-static scheduling with G link as an example: Scenario 1 (Case 1), the fourth symbol of each wireless frame is used for data transmission. If the data packet is ready at the first symbol, the data packet can be sent only after 3 symbols, with the transmission delay less than 20.833 μs, because the latest resource available for transmission is at the fourth symbol. In Scenario 2 (Case 2), assuming that the packet is ready after the third symbol of the current wireless frame, the packet is sent at the fourth symbol of the next wireless frame, and the longest transmission delay of the packet is only 20.833 μs.

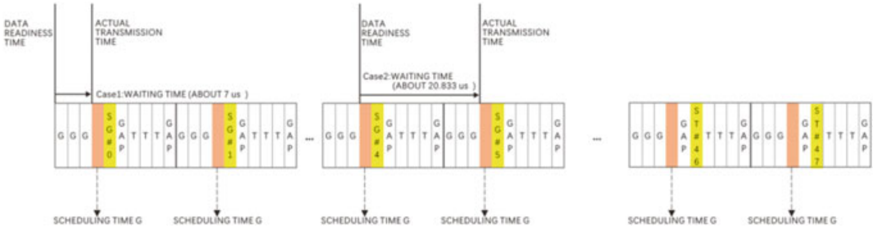


Fig. 10 Packet sending diagram

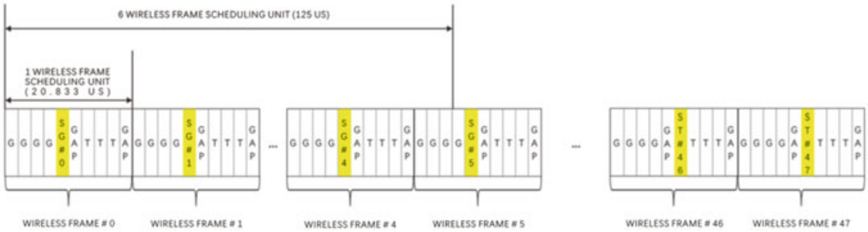


Fig. 11 Schematic diagram of packet scheduling unit (period)

- Overhead resources evenly distributed signal, as shown in Fig. 10, overhead signals (such as sync signal, broadcast information, control information, access to information, ACK feedback information, etc.) the physical resources across multiple wireless transmission in the frame, to ensure that each wireless frame has resources transmission G link packet and a link.
- Ultra-short flexible scheduling period: The star flicker system supports two types of scheduling unit (period) configurations. Ultra-low latency data transmission supports the shortest scheduling period of wireless frame duration (20.833 μs). Each wireless frame contains at least one transmission opportunity of G link and T link, and the minimum transmission delay is one wireless frame duration (20.833 μs). Large packet/high traffic data transmission supports a minimum unit of 6 wireless frame scheduling cycles (125 μs). See Fig. 11.

6 Channel Coding and Modulation

6.1 Data Transmission Channel Coding

Polar code is a channel code constructed on the basis of channel polarization theory. It is a channel code that can reach Shannon limit after theoretical analysis and demonstration, and can better resist random errors. RS code is a linear block code, which is based on the multi-base channel code of Galois Field. Each symbol can contain

Table 3 Ultra low delay data transmission modulation coding

Bits	Encoding block length (including 8 bits CRC)	Channel coding scheme	Modulation method
16bits	24bits	RS (15,11) truncated (10,6) or Polar	QPSK
			16QAM
			64QAM
			256QAM
			1024QAM
24bits	32bits	RS (15,11) truncated (12,8) or Polar	QPSK
			16QAM
			64QAM
			256QAM
			1024QAM
32bits	40bits	RS (15,11) truncated (14,10) or Polar	QPSK
			16QAM
			64QAM
			256QAM
			1024QAM

more than one bit. It has good anti-burst interference performance and can better resist continuous errors. The system uses Polar code or RS code to transmit small packet services with ultra-low delay (such as vehicle-mounted active noise reduction) to ensure that the system can achieve highly reliable transmission in different application scenarios. The specific coding and modulation combinations are shown in Table 3.

6.2 The Physical Layer HARQ

Hybrid ARQ (HARQ) is a combination of FEC and ARQ to increase the transmission reliability of links. In traditional ARQ, when the receiving end detects an error in the received information, the receiving end directly discards the error packet and requests the sending end to retransmit the corresponding packet. Compared with ARQ, HARQ enhances ARQ. That is, the received error packet information is not discarded, but is combined with the retransmitted packet information to improve the receiving reliability.

The system adopts Polar code based asynchronous HARQ technology, supports up to four HARQ processes, and supports CC-HARQ scheme and IR-HARQ scheme. The benefits of CC-HARQ scheme come from multiple soft information merging at the receiver, which improves the equivalent SNR of the information at the receiver and reduces the error probability. In IR -HARQ scheme, according to the characteristics

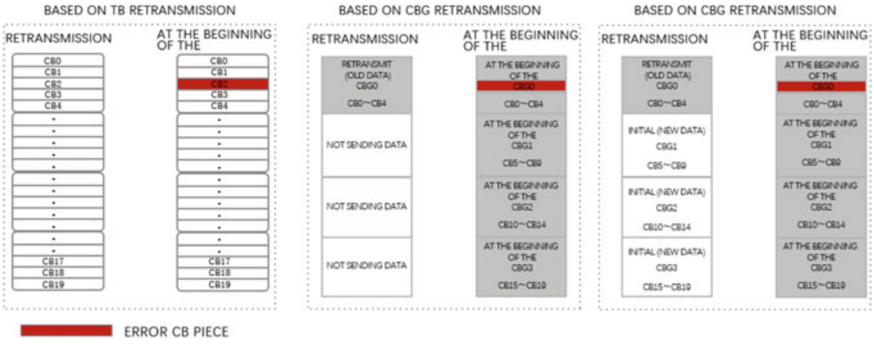


Fig. 12 HARO scheme

of Polar code, the length of the master code is extended during retransmission or the encoding bits not sent during the first transmission are sent, and the encoding gain is further obtained on the basis of the energy gain.

The system supports three retransmission schemes: retransmission based on TRANSFER block (TB), retransmission based on code block group (CBG) and mixed retransmission based on CBG.

TB retransmission means that if any CB in a TB fails, the data in the entire TB is retransmitted. During the retransmission, the number of CB segments C is the same as that in the first transmission, but the channel bits of each CB may be different from those in the first transmission.

CBG retransmission for each CB, the implementation process is the same as TB retransmission. Different from TB retransmission, CBG retransmits only the CBG where the CB error occurs.

CBG mixed retransmission refers to the CBG retransmitted by the previous TB and the CBG initially transmitted by the new TB. Segment number C is the same number of block segments contained in the last TB initial transmission associated with this transmission. All incoming CBGS form a new transport block (TB) (Fig. 12).

7 Multi-Domain Collaborative

7.1 Multi-Domain Synchronization

The system reduces interdomain interference through time/frequency synchronization between multiple G nodes. The star flicker system adopts OFDM waveform. In the scenario where multiple communication domains exist, even if different communication domains use different frequency points, if the frequency difference is not an integer multiple of the sub-carrier interval SCS = 480 kHz or the timing difference exceeds CP, interference between sub-carriers will be caused. In particular, when the interference comes from multiple communication domains and the interference source is much closer to the receiving device than the signal source, the interference introduced by time–frequency misalignment between G nodes can significantly reduce the received signal-to-noise ratio. Time/frequency synchronization between multiple G nodes can significantly reduce the interference between multiple domains and improve the spectral efficiency when multiple domains coexist.

The system needs to consider multiple communication domains in the same physical space. In a dense deployment scenario, the path loss from the interference source to the receiver may even be significantly smaller than that from the signal source to the receiver. Taking two communication domains using adjacent carriers as an example, considering the same transmitting power of G nodes in the two domains, the path loss from the interference source to the receiver from other domains is 20 dB smaller than the path loss from the signal source to the receiver. When the two domains are synchronized, and the frequency synchronization error is 100 Hz, for example, the power leaked from the interference source to the carrier relative to the interference source is less than −74 dB, the received signal dry ratio is higher than 54 dB (74–20), and the interference can be ignored. When the two domains are asynchronous, generally, only filters can be used to suppress the adjacent frequency interference. The power leaked from the interference source to the carrier is about 20 dB relative to the power of the interference source, and the received signal dry ratio is about 0 dB (20–20). It is not difficult to see that time/frequency synchronization between multiple G nodes can significantly reduce the interference between communication domains, especially the interference between communications domains located on adjacent carriers.

Time/frequency synchronization between multiple domains and multiple G-nodes can be completed by sending synchronization information and listening behavior of g-nodes. Figure 13 takes five G nodes as an example. The startup sequence is G1, G5, G4, G2, and G3, showing the process of realizing time–frequency synchronization in five domains.

- First of all, G1 and G5 nodes are not overwritten by any synchronization set when they start up, so the red synchronization set and blue synchronization set are established respectively.
- Then, with the startup of G2 node and G4 node, the number of nodes in red synchronization set and blue synchronization set gradually increases, and the coverage is gradually expanded to cover G3 node.
- Next, when G3 is powered on, the red synchronization set and blue synchronization set are listened to, and both synchronization sets have two nodes. G3 is closer to G4 node, so the blue synchronization set has stronger coverage on G3, and G3 is added to the blue synchronization set.
- At last, G2 nodes and G1 nodes are successively transferred from the red synchronization set to the blue synchronization set with more nodes. Finally, all nodes are in the blue synchronization set and the synchronization is completed.

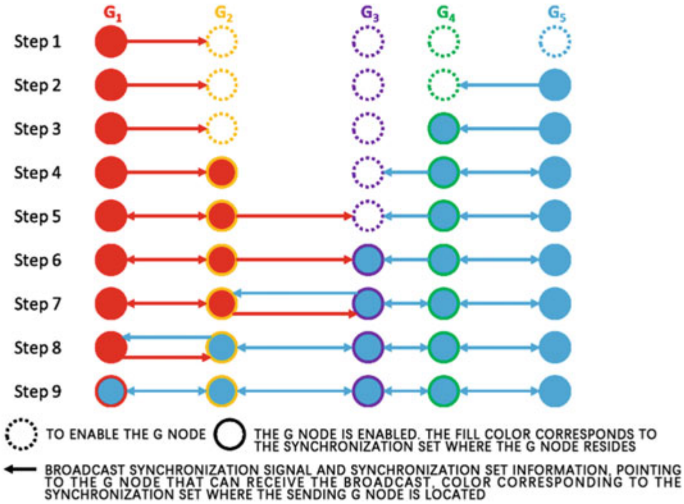


Fig. 13 Schematic diagram of multi-node time–frequency synchronization process

7.2 Multi-Domain Resource Coordination

The system supports G nodes in advanced communication domains to allocate resource pools to other communication domains through broadcast to achieve multi-domain resource coordination. Resource pools in different communication domains can use different carriers, and resource pools in different communication domains on the same carrier can use different symbols. On each carrier containing the advanced communication domain, the G node of the advanced communication domain instructs different communication domains to use the resource pool with orthogonal time domain through the system message, so as to avoid the communication links of different communication domains using the same resource.

Figure 14 shows an example of resource usage over two communication domains on the same carrier. In the resource pool of the communication domain:

- The resources used for data transmission (G symbol and T symbol in the figure) are allocated in symbol granularity and repeated in wireless frame cycle.
- The resources used for overhead transport (the S symbol in the figure) are allocated at overhead symbol granularity, repeating in superframe cycles.

When the resource pools of different communication domains are different, G node of the communication domain sends synchronization signals and transmits service data in the resource pool of its own communication domain. Then, the G node can receive synchronization signals of other domains in the resource pool of other communication domains to achieve inter-domain synchronization tracking, without affecting service transmission in the communication domain.

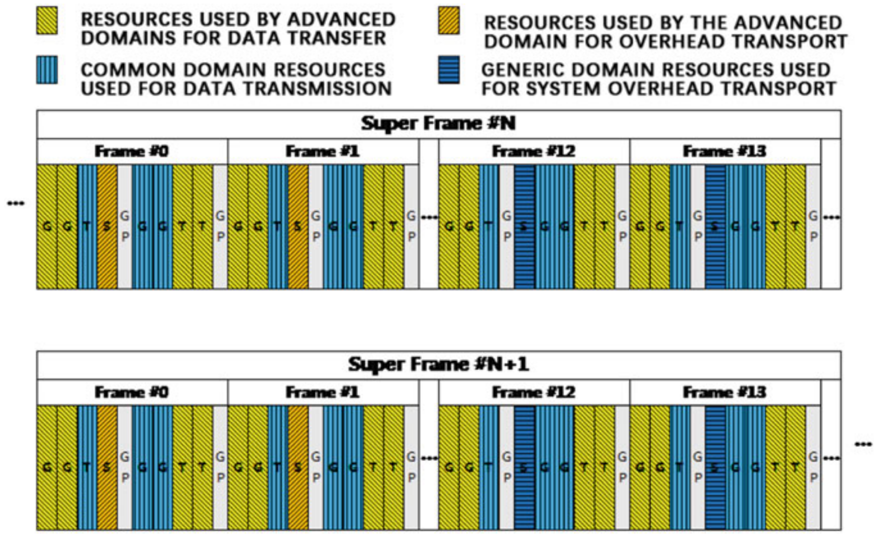


Fig. 14 Diagram of multi-domain resource coordination

8 Conclusion and Outlook

In conclusion, the system can satisfy the ultra-low delay application in vehicle-mounted application scenarios by defining ultra-short timeslot frame structure and ultra-short wireless frame scheduling period (20.833 μs). High-performance channel coding, physical layer HARQ retransmission and discrete single carrier scheduling technologies can achieve highly reliable transmission, meet the requirements of 99.999% or more highly reliable applications, and realize the replacement of terminal wired connections. Multi-domain collaboration technology improves resource efficiency and reduces interference between networks. Minimalism and high security information features are designed to meet the needs of high security applications.

Future system will be at a higher efficiency, lower power consumption, larger bandwidth, more antennas and other technical direction for continuous evolution, and support range, more functions, such as networking launch with higher speed, lower cost, lower power consumption, and further the coverage of the evolution of the system, better support all kinds of application scenarios, in short distance wireless applications play a bigger role.

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