ZiFiSense
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ZETA Communication White Paper

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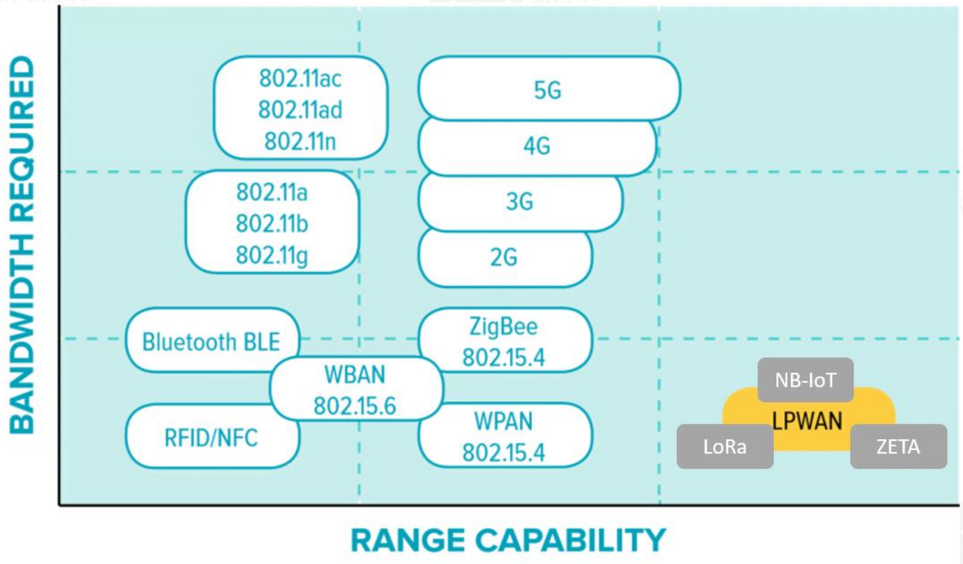
1. Introduction

This article is mainly to introduce our ZETA technology, a LPWAN (Low Power Wide Area Network) protocol standard based on UNB (Ultra Narrow Band) technology. The ubiquitous IoT scenarios has requirements of few data transmission, low connection cost, adjust complex environments, etc. The ZETA technology perfectly fits these requirements with characteristics of wide area connection, low service cost, low power consumption, etc.



2. ZETA Overview

The ZETA protocol defines the physical layer, data link layer and network layer of the OSI model, providing functions of Communication Coding, Access Control, Device Authentication, QoS Secure, Encryption of every node in the ZETA network.

The following section will focus on several key point of ZETA protocol: General structure, characteristics, branch protocol features, network safety solution and the physical layer technology.

3. ZETA Protocol Analysis

3.1. ZETA Network Structure

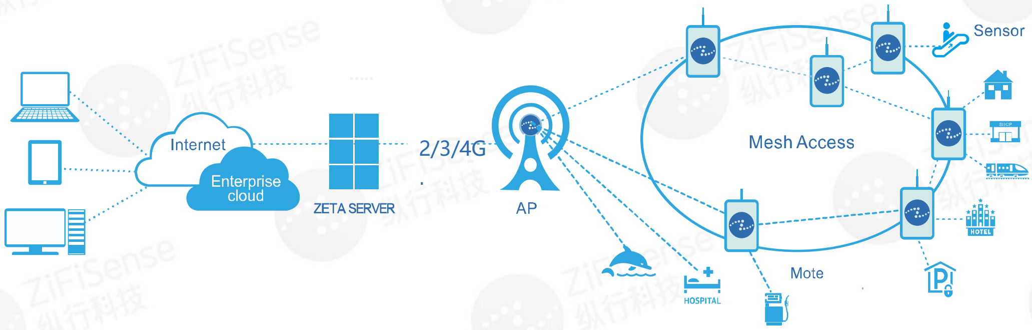


Figure 1 Network Structure

The basic ZETA network structure is the typical star topology. But in order to satisfy demands of different IoT scenarios and facilitate implementation, we created the tree topology structure with MESH ACCESS. Furthermore, we designed three branch protocol to meet requirements of different scenarios:

ZETA-P: For scenarios require short transmission latency, large data amount while have small capacity of devices connected.

ZETA-S: For scenarios requires big capacity of devices connected, small data amount, but low requirement of transmission latency.

ZETA-G: For scenarios of one-way transmission, non-reliable transfer. Lead to a very low cost of module.

The ZETA network includes elements of AP, Mote, MS, and Cloud Platform. Among them, AP, MS, and Cloud Platform are obligatory elements, Mote is an optional element.

3.1.1. AP

AP(Access Point), is the rendezvous point of data in ZETA network system, responsible for collect data generated in the ZETA network and uplink the data to server. It supports FOTA (Firmware Over-The-Air) upgrade and remote configuration.

3.1.2. Mote

A low power smart routing node for the Mesh access design. It can significantly improve the signal coverage of one single AP, replenish signal at blind spots and prevent data clogging.

- **Low power consumption design**: Battery supply can last for over 3 years with typical network connections.
- **Self-organizing network**: Access the network automatically after power on without configuration.
- **Self-healing connection**: Mesh nodes can re-organize the topology to heal the entire network when one route of the network lost connection, ensure the reliability of the data transmission.
- **Multi-hop**: Depend on the branch protocol selected can support at most 4 hops to extend the AP signal to remote positions.
- **Smart routing**: Smartly choosing best topology and communication dispatch strategy to reduce the power consumption to the lowest level possible.

3.1.3. MS

MS (Module&Sensor), data passthrough module, connect externally to integrated into sensors.

- **Low power two-way communication**.
- **Self-organizing network**: Access the network automatically after power on without configuration.
- **Self-healing connection**: Mesh nodes can re-organize the topology to heal the entire network when one route of the network lost connection, ensure the reliability of the data transmission.
- **Smart routing**: Smartly choosing best topology and communication dispatch strategy to reduce the power consumption to the lowest possible.
- Ample instruction set in UART passthrough mode, can query signal quality of the module, status, network time, set to test mode, etc.

3.1.4. ZETA Server & PaaS

ZETA Server is used for ZETA network management, it offers functions of complex protocol analysis, topology display, current power condition of devices query, protocol version query, OTA, etc.

PaaS platform, provide standard API interface, easy for clients to docking the platform and acquire data.

To reduce development and docking workload, the platform integrated with ZETA network management.

The ZETA server is easy to use for locating the network problem remotely, significantly reduce labor cost of troubleshooting.

General API interface, easy to read.

Platform docking can be completed within 5 minutes with our standard SDK provided.

Support Private cloud, Public Cloud and Mixed implementation.

3. 2. ZETA Protocol Characteristics

3.2.1. Ultra-Narrow Band Communication

The ZETA protocols using ultra-narrow band for communication, the bandwidth of one single channel is only 3.8K. With flexible options of data rate, supporting not only the typical 100/300/600bps but the fastest rate can reach 50kbps. The entire system occupies very limited frequency band resource with less than 30K, thus is very convenient to apply on the license-free spectrums of countries all over the world.

3.2.2. Two-way communication

All ZETA protocols (except ZETA-G) support two-way communication. The uplink transmission reports data generated in the sensors and downlink transmission send configuration, query, or control command to sensors.

3.2.3. Low Power Consumption

ZETA protocols made several low power consumption designs such as LDC, ack downlink, period downlink, sensor sleep mode, time slot uplink. These designs are direct at characteristics of IoT applications of mainly uplink transmission, small data volume, low reliability, and low real-time requirements.

3.2.4. Long Coverage Distance

ZETA protocols allow nodes in the ZETA network communicate with each other from over 10Km vision distance. In case of using multi-hop Mote, the coverage is further extended. As for ZETA-G protocol, we apply the SDR (Software Defined Radio) technology and enhance the uplink sensitivity with several algorithms such as orthogonal FSK + TBCC + Repeat, effectively extend the coverage in a different way.

3.2.5. Anti-interference

ZETA protocols are applied on license-free spectrums which have a lot of interference signals. We designed frequency hop and Carrier Sense functions to improve the anti-interference performance of the protocols.

3.3. ZETA Branch Protocols Features

This section is mainly to introduce functions and basic features of three branch protocols: ZETA-P\ZETA-S\ZETA-G

3.3.1. ZETA-P

Random network access and data transmission

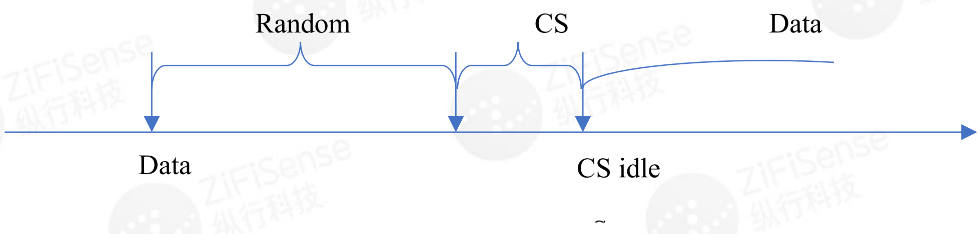


Figure 2 Random transmission

When devices using ZETA-P need to register to the network or transmit data, it will randomly retreat for a while to do the Carrier Sense. If the Carrier Senses' result is idle, the device will send register request or transmit the data.

Reliable Transmission

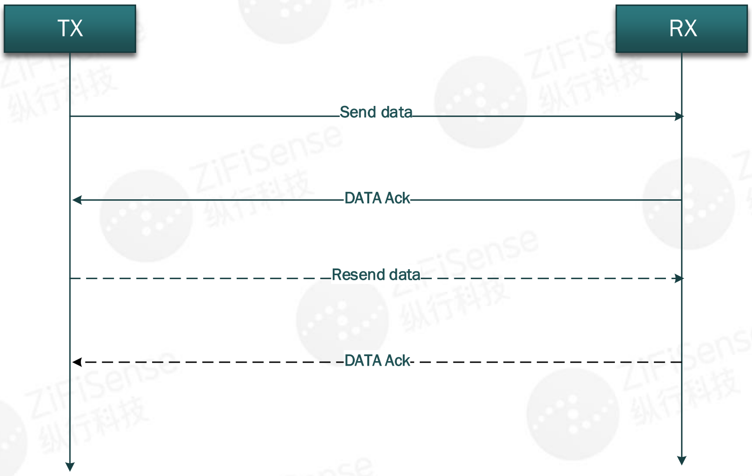


Figure 3 Reliable Transmission

Except for the ZETA-G protocol, all the other branch protocols use the Ack frame design to ensure the data reception on the receptor node, it's a design of reliable transmission. If the device didn't receive the Ack frame from the receptor node after transmission, it will repeat the data transmission to ensure the data arrive the target node correctly.

Carrier Sense

To improve the usage rate of channels and avoid network congestion, devices will realize a Carrier Sense before transmit data, and only start the transmission when detect the channel idle. The procedure is as follow:

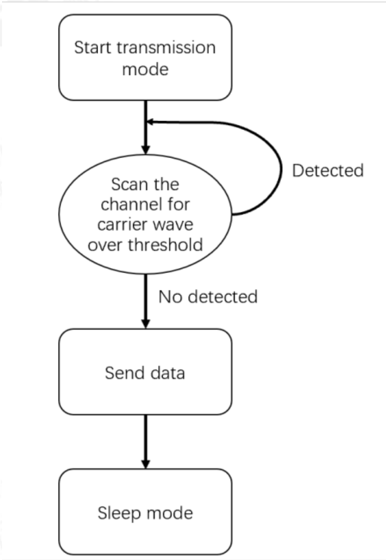


Figure 4 Carrier sense procedure

Attribution Verification

In real using cases, multiple enterprises could use the same branch protocol and frequency point, that will lead to cross registration from device to other enterprises' AP. To avoid this situation and protect data, user can enable the attribution verification function, to verify the device's attribution when start the registration. The procedure is as follow:

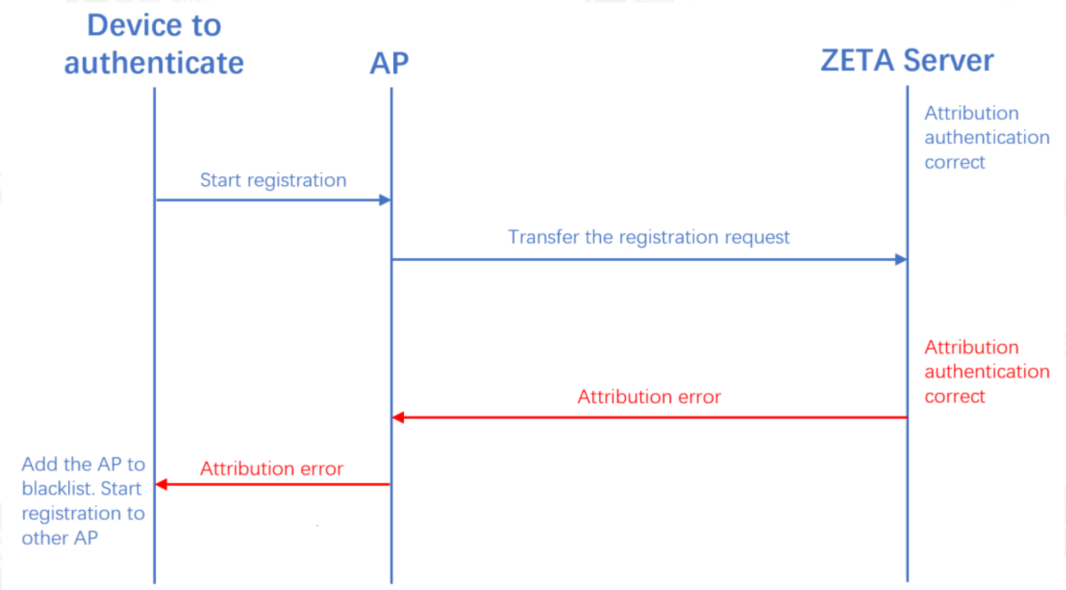


Figure 5 Attribution Verification Procedure

Network Self-healing

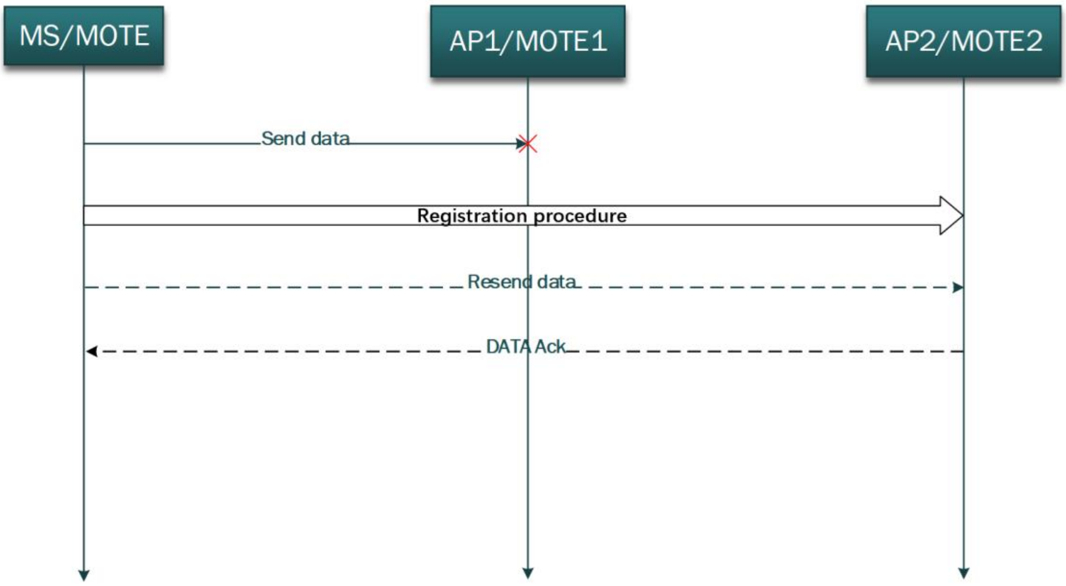


Figure 6 Network Self-healing

The ZETA-P branch protocol possesses network self-healing function. That means when an error occurs in a link path of the network, affected nodes can automatically choose another available link path to complete the data transmission.

Large Data Transmission

Based on the feature of random transmission, ZETA-P protocol can transmit large application layer data up to 50Bytes.

Short Latency

Random data transmission has very low possibility of transmission conflict when small number of devices were connected to the network using ZETA-P protocol. When data was generated, the uplink and downlink transmission respond in a very short time, the latency is more dependent on the Air Interface Speed.

OTA

The OTA function is available for ZETA-P protocol when upgrades like bug fix, adding new feature is needed. Clients can use this wireless upgrade method at near field or remotely.

3.3.2. ZETA-S

Registration and Data Transmission at Time Slot

The ZETA-S protocol uses separated time slot and frequency points to manage the Air Interface resources. Time will be equally divided into time slots; every time slot is 900ms or longer. At the same time, configure multiple frequency point for every network system, each frequency point is used for uplink or downlink communication of only one node type of MS/Mote/AP.

Every device will be assigned a working time slot when register to the network, in case of the system have many devices, multiple devices could be assigned at the same time slot, so they need to compete when try to send data at the same time. There is still a certain possibility of transmission conflict but significantly reduced compared to random transmission system.

A creatively function for the Mote is the Time Slot Multiplexing. Since we have configured multiple frequency points in the ZETA network system, transmission on different frequency point can be done at the same time slot. For example, in one ZETA network system, transmission from MS node to Mote and from Mote to its superior node use different frequency point, so Mote A can receive uplink data from MS node at the same time slot when Mote B send uplink data to its superior. In this way, the capacity of ZETA network increases even bigger.

Registration and data transmission procedure (take example of MS register to AP):

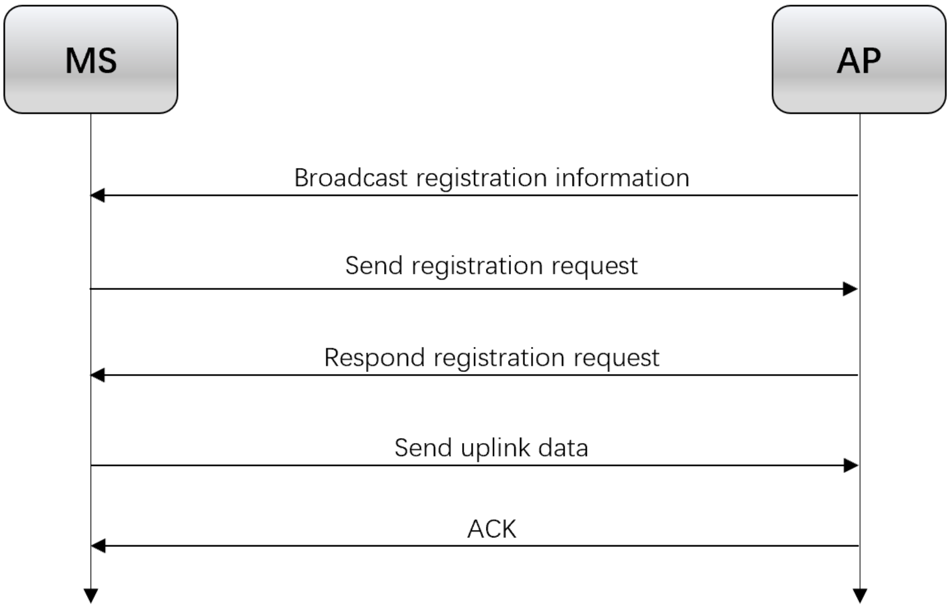


Figure 7 Registration and data transmission procedure

A. AP periodically broadcast registration info.

B. MS listen to broadcast from AP before start registration procedure. After receive broadcast from 1 or more AP, MS will choose one AP based on the registration selection algorithm and send registration request to the AP.

C. AP will start both related resource assignment and authentication procedure after receiving the registration request from MS, when the assignment and authentication finished, AP reply to MS the registration request and finish the entire procedure of registration. Transmission can be realized from this moment.

D. After successfully registration, the MS will send data to AP when data was generated.

E. AP reply with an Ack frame when receive data.

Reliable Transmission

Except for the ZETA-G protocol, all the other branch protocols use the Ack frame design to ensure the data reception on the receptor node, it’s a design of reliable transmission. If the device didn’t receive the Ack frame from the receptor node after transmission, it will repeat the data transmission to ensure the data arrive the target node correctly. The procedure can use ZETA-P for reference.

Carrier Sense

ZETA-S protocol support Carrier Sense function to reduce transmission conflict probability. The procedure of Carrier Sense is done in the GAP time. The GAP time is formed by DIFS and several CS-SLOT.

1: The sender device will process and prepare the Mac layer message within DIFS time, then start Carrier Sense procedure. Generate a retreat value which not surpass the max value of entire channel window and not less than the retreat value of high priority transmission window.

2: Device will constantly scan the channel while in retreat procedure; if no carrier wave was detected when retreat time finish, device obtain channel using right and start transmission procedure to send data immediately; Otherwise, the device start retreat procedure again and wait to send data at next channel window.

Frequency Hop

ZETA-S supports frequency hopping to improve system interference resistance. The system divides the available frequency points into several frequency groups in advance. When the device is connected to the network, it will get the frequency hopping frequency point group and the current frequency point from the higher level, and then hop the frequency within the frequency hopping group according to the pre-agreed frequency hopping sequence. This enhances the system security since it improves the anti-interference and also has certain anti-frequency tracking.

Attribution Verification

In real using cases, multiple enterprises could use the same branch protocol and frequency point, that will lead to cross registration from device to other enterprises' AP. To avoid this situation and protect data, user can enable the attribution verification function, to verify the device's attribution when start the registration. The procedure can use ZETA-P for reference.

Network Self-healing

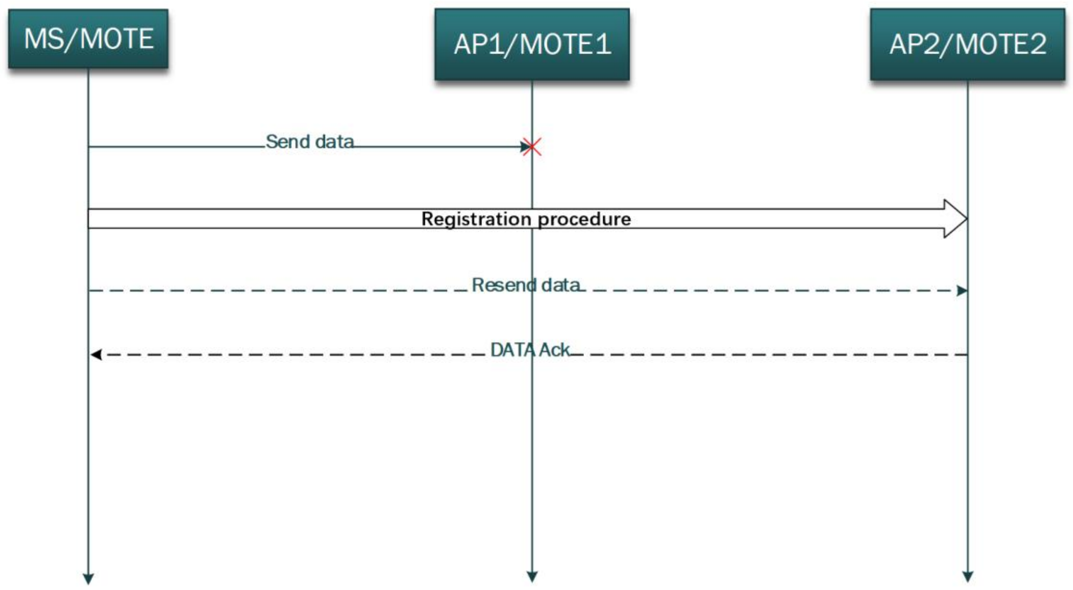


Figure 8 Network Self-healing

The ZETA-S branch protocol possesses network self-healing function. That means when an error occurs in a link path of the network, affected nodes can automatically choose another available link path to complete the data transmission.

Small Data Volume

Each data transmission of ZETA-S is finished in one time slot. So, when the time slot is configured at 900ms, it only allows 8Bytes application layer data.

Large capacity

The management of Time Slot and Frequency Points improves the channel utilization and enhance the capacity of ZETA network system. For the ZETA-S protocol, theoretically one single AP can support 90,000+ devices.

Metropolitan Area Network (MAN)

The neighbor APs in the ZETA-S protocol can use GPS synchronization to avoid interference from each other. With this mechanism, metropolitan network or even across country implementation is possible to apply.

OTA

The OTA function is available for ZETA-S protocol when upgrades like bug fix, adding new feature is needed. Clients can use this wireless upgrade method at near field or remotely.

3.3.3. ZETA-G

Carrier Sense

To improve the usage rate of channels and avoid network congestion, devices will realize a Carrier Sense before transmit data, and only start the transmission when detect the channel idle. The procedure is as follow:

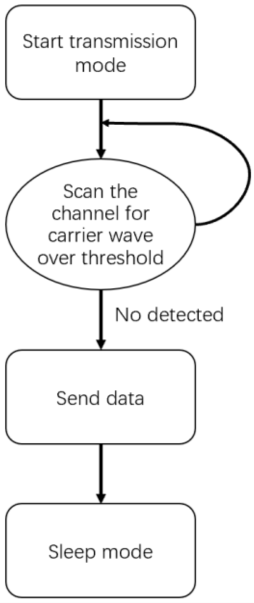


Figure 9 Carrier Sense Procedure

Minimalist Protocol

The ZETA-G protocol has a very simple structure due to its designed for one-way transmission applications. Since the protocol contains no downlink transmission, devices in the ZETA-G network system have very low power consumption.

Large Capacity

The ZETA-G protocol is designed for one-way transmission scenarios like logistics and property management with large capacity requirement. With the multi-channel reception function of the SDR AP, a single physical antenna can receive data from 64 channels to expand greatly the capacity of ZETA network system.

3.4. ZETA Protocol Security

3.4.1. Registration authentication

The registration authentication is a necessary part of device registration procedure to avoid non-ZETA device register to the network. Device calculate an *Auth* value use a random *nonce* and the integrated secret key *KI*, then send both *nonce* and *Auth* to NS platform. The platform will do the same calculation using the *nonce* received from device to get another *Auth*, then compare it to the *Auth* received from device to verify if they match.

3.4.2. Communication encryption algorithm

Not like Internet, IoT network have smaller data volume but more sensitive to network redundancy and network overhead. That requires a more lightweight encryption algorithm to encrypt and secure sensitive data.

ZETA protocols use a lightweight encryption algorithm Keeloq to encrypt data field of the message. The mechanism works as: Use an 8byte key to encrypt n*4byte plaintext, get a n*4byte ciphertext at sender end; then use an 8byte key to decrypt n*4byte ciphertext into the origin n*4byte plaintext at receiver end.

3.4.3. Authentication and data encryption

The authentication process is: The AP generate an authentication summary using SHA256 algorithm with BSSID, random number count, and secret key KI integrated in AP. Then encrypt the count and the authentication summary using AES128 algorithm with KI and send to platform. The platform decrypts the authentication summary using the same algorithm after received it and proofread it. After the verification is passed, platform reply “login success” to AP. The gateway will use RS1024 to generate a key pair and send the public key to the cloud platform, which randomly generates 128bits data communication key, encrypts it with the public key and sends it to the gateway. The gateway uses the private key to decrypt and get the data communication key. Subsequent communication with the cloud platform will use this key to encrypt communication using aes128.

4. ZETA Physical Layer Technology

This chapter is mainly to introduce the physical layer technology Advanced M-FSK modulation and its unique characteristic: it possesses the advantage of narrow band communication of Sigfox, also extensibility of LoRa, while can use 5G technology to complete transmission at relative high rate in a small bandwidth.

4.1. M-FSK Modulation Technology

M-FSK Modulation: a signal with time domain of 1 will Select a frequency point to modulate and transmit on M orthogonal frequency points in the frequency domain. As the picture below, M=8, every symbol of every frequency point can modulate 3-bit information. The minimum frequency interval should be 2kHz to ensure it's bigger than the orthogonal symbol rate. As for the picture, symbol rate should be 600Hz.

The following insights can be obtained intuitively:

1, The modulation information is changed only in phase, no information is modulated in amplitude, the PAPR is zero to maintain the low power consumption characteristics. **2,** While the transmit power remains the same, if the bandwidth increases, the modulation bits increase (log2(M)). **3,** Each symbol is sent at only one frequency point as narrowband communication characteristics.

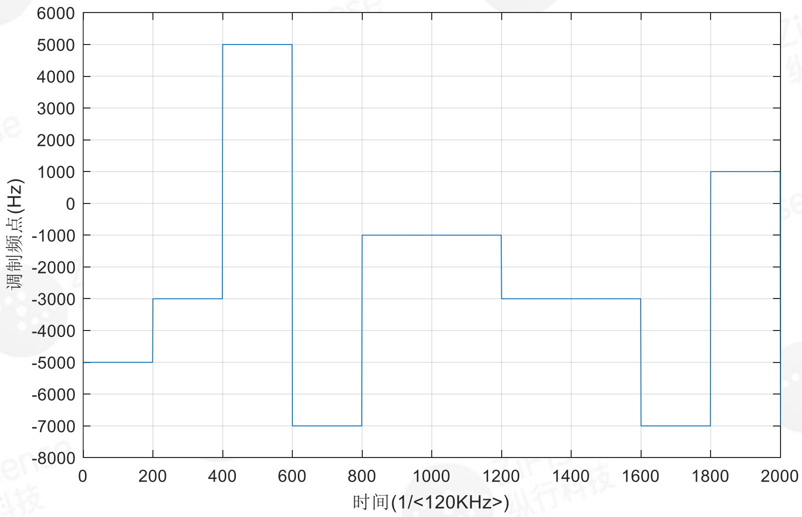
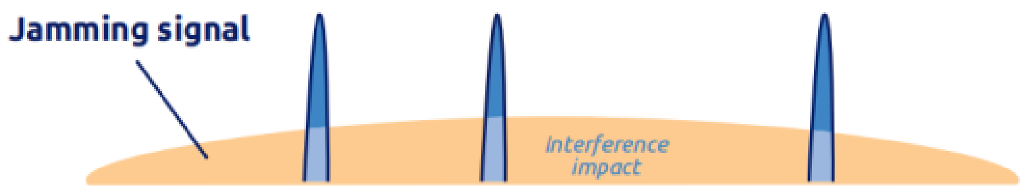


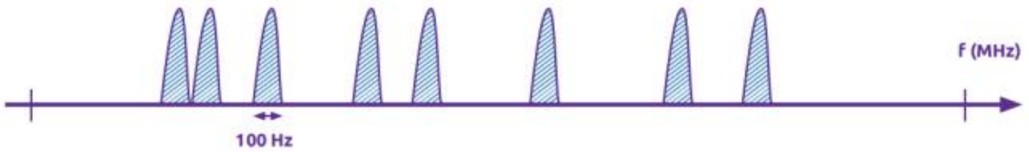
Figure 7 M-FSK modulation

4.2. Advantage of narrow band communication

Because of the use of narrowband transmission, the energy is very concentrated in the frequency domain, so it has very good anti-interference characteristics, including signal interference based on spectrum expansion



Sigfox is an ultra-narrow band communication with transmission rate at 100Hz. When symbol rate of M-FSK is as small as 100Hz, for each symbol the signal occupies very small bandwidth in frequency domain. Just like Sigfox, the energy is very concentrated, so M-FSK possesses an equally transmission ability of Sigfox's narrow band communication.



NB-IoT has multiple uplink transmission method: one of them is SC-FSMA with relatively high power consumption; another one is also similar to **Sigfox**, using narrow band communication similar to single frequency point transmission, but with faster symbol rate at 3.5kHz, achieve the long range coverage using repeat transmit method. Transmission gain of repeat transmit reaches the maximum only when carrier waves are fully coherent, but in single carrier wave communication, it's difficult to achieve fully coherent. So, NB-IoT has a slightly worse performance at extreme coverage, which inevitably leads to higher power consumption as well.

4.3. Supports scalable coverage and rates

M-FSK Modulation technology has following parameters： Total transmission frequency domain bandwidth—BW (Excluding protection bandwidth), Sub-Carrier space—SCS, Code Rate—CR. We can use SCS and BW to calculate Frequency Domain Factor $\mathrm{K}=\log_2^{\mathrm{BW/SCS}}$; To ensure orthogonality between frequency points, the symbol duration is at least $1/\mathrm{SCS}$.

The spectrum efficiency and bit rate are determined based on the frequency domain factor K, coding rate, total transmission frequency domain bandwidth and symbol duration. The specific derivation process is:

Frequency domain factor K:

$$\mathrm{K}=\log_2^{\mathrm{BW/SCS}} \Rightarrow BW=2^k * SCS \quad (1)$$

Bit rate:

$$DR=\frac{K}{\frac{1}{SCS}} * CR = K * SCS * CR \quad (2)$$

Spectrum efficiency:

$$\eta=\frac{DR}{BW}=\frac{\mathrm{K} * \mathrm{SCS} * \mathrm{CR}}{2^k * SCS}=\mathrm{K}/2^{\mathrm{K}} * CR \quad (3)$$

In comparison with LoRa, the parameters of Advanced M-FSK have a one-to-one correspondence with parameters of LoRa. The technology of LoRa uses a special method of spread spectrum, while Advanced M-FSK uses a frequency point modulation technology similar to OFDM in 5G. So advanced receiver technology of 5G can be used as reference to ensure a high-level reception sensitivity.

Sheet 1 Key parameters comparison of Advanced M-FSK and LoRa

	LoRa	Advanced M-FSK	Note
Modulated bits	Time domain factor—SF	Frequency domain factor—K	
Signal	CSS(Chirp-Spread-Spectrum)	1	Advanced M-FSK can flexibly support phase modulation
Bandwidth	BW	$\mathrm{SCS}\times 2^{\mathrm{K}}$	
Sub-Carrier space		SCS	Corresponding to $1/\mathrm{BW}$ of LoRa
Chip duration	$1/\mathrm{BW}$		Corresponding to SCS of Advanced M-FSK
Symbol duration	$2^{\mathrm{SF}}/\mathrm{BW}$	$1/\mathrm{SCS}$	

Bit rate	$BW \times SF/2^{SF} * CR$	$K * SCS * CR$	
Spectrum efficiency	$SF/2^{SF} * CR$	$K/2^{K} * CR$	

Different rate and coverage are supported to adjust application of different IoT scenarios. Take example with 120kHz transmission bandwidth, the rate and the coverage changes under different SCS parameter. Smaller rate corresponds better coverage.

Sheet 2 Relation of SCS and Rate of Advanced M-FSK

SCS	Bandwidth	Rate
15kHz	120kHz	45kbps
7.5kHz	120kHz	30kbps
3.75kHz	120kHz	18.75kbps
3.75/2kHz	120kHz	11.25kbps
3.75/8kHz	120kHz	3.75kbps

4.4. Support high-rate transmission

The Advanced M-FSK have characteristics of OFDM while maintains low power consumption, thus it possesses technical features of 5G: One is the scalable Sub Carrier Space mentioned in previous section, the Sub Carrier Space become bigger at higher transmission rate, it allows to reach SCS=60kHz for example; another one is adding phase modulation information such as BPSK/QPSK/8PSK to each symbol transmit frequency to meet the requirement of PAPR=0db while improve the spectrum efficiency and increase transmission rate.

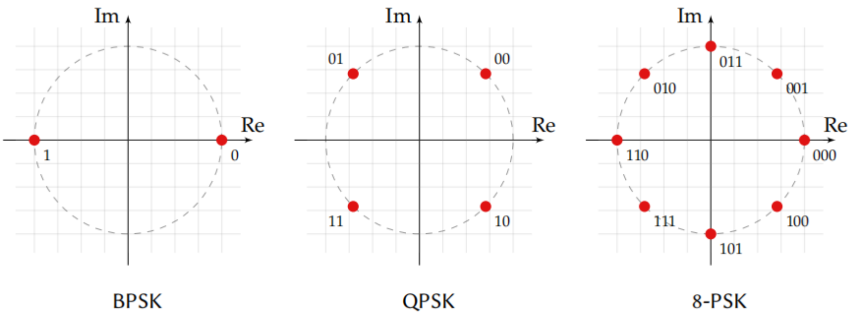
Compared to LoRa, the frequency domain factor K of Advanced M-FSK is more flexible. Similar to 5G, to improve transmission rate, the SCS should be increased by reducing K.

Sheet 3 Relation of SCS and Rate of Advanced M-FSK

Bandwidth	K	CR	SCS	Rate
120kHz	2	1	30kHz	60kbps
120kHz	3	1	15kHz	45kbps

The mechanism of LoRa is also choose a desired transmission rate by changing bandwidth and time domain factor—SF. Theoretically, the transmission rate reaches the highest when SF=1. But in real case, there is no product in the market have SF value less than 6. The reason is a complete CSS is difficult to transmit in short time like SF=1. But Advanced M-FSK has no limitation to the frequency domain factor, so it has better extensibility.

Another advantage of Advanced M-FSK when compared to LoRa is the phase modulation. Just like 5G, Advanced M-FSK can improve spectrum efficiency by adding phase modulation. 5G technology uses QAM modulation, that's a method to modulate information on both phase and amplitude. To secure the energy efficiency, Advanced M-FSK only adds phase modulation, but LoRa can't modulate information on phase as it shows in sheet 1. LoRa can only send CSS signals, this signal does not have any other modulation information, so no additional bits can be sent. The following diagram shows the phase modulation, 3 additional bits per symbol can be sent with 8PSK.



The following sheet shows the rate obtained by adding phase modulation under different bandwidth

Sheet 4 The effect of different phase modulation on the rate

Bandwidth	K	CR	SCS	No Phase Modulation Rate	Modulation	Phase Modulation Rate
960kHz	4	1	60kHz	240kbps	32-PSK	540kbps
120kHz	1	1	60kHz	60kbps	32-PSK	360kbps
120kHz	2	1	30kHz	60kbps	32-PSK	210kbps
120kHz	2	1	30kHz	60kbps	8-PSK	150kbps
120kHz	3	1	15kHz	45kbps	BPSK	90kbps
120kHz	4	1	7.5kHz	30kbps	None	30kbps

From the above description, Advanced M-FSK has higher spectrum efficiency compared to LoRa, and is easier to expand in bandwidth, also it can modulate information in phase. It enables Advanced M-FSK to meet the application scenarios with higher data volume requirements within the limited bandwidth of sub 1GHz compared to LoRa.