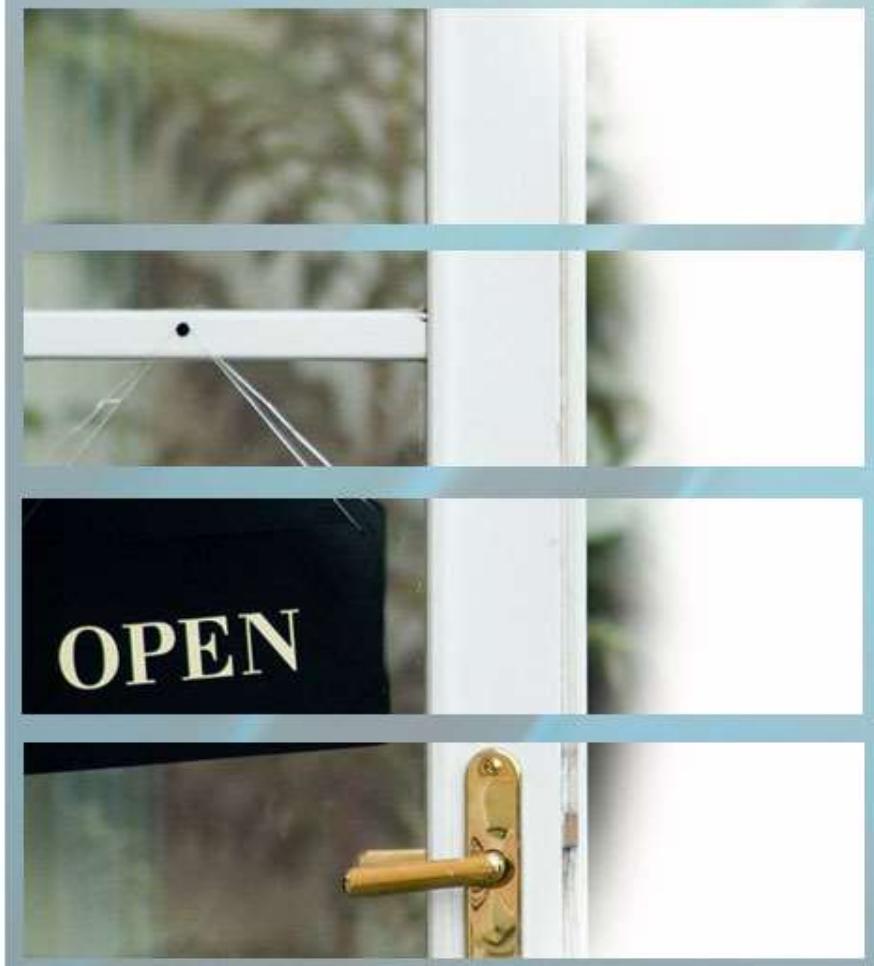
Chapter Eight

Wireless Low Speed Network



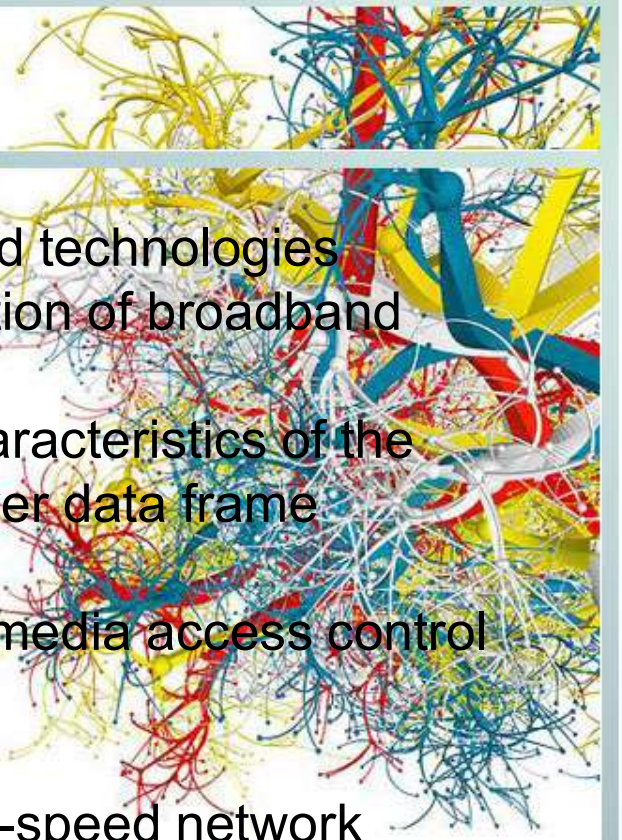
Greater connectivity is one of the features of the Internet of things.

Wireless low speed network protocol can adapt to the characteristics of less intelligent devices in the Internet of things.

This chapter will introduce the typical wireless low speed network protocol and wireless sensor network networking technology.

内容提要

Review



Chapter 7 introduces typical wireless broadband technologies

- New features of wireless channel and definition of broadband network
- Wi-fi /802.11 architecture, physical layer, characteristics of the media access control layer, and data link layer data frame structure.
- WiMAX/802.16 architecture, physical layer, media access control layer characteristics and protocol.

This chapter introduces the typical wireless low-speed network transmission protocol (Bluetooth/Infrared /802.15.4&ZigBee), and discusses the implementation of wireless sensor network in detail.

Content

8.1 Low speed network protocol requirements

8.2 Wireless low speed network protocol

8.3 Implementation of wireless sensor network protocol

8.4 IPv6 Internet connectivity

Why does the Internet of things need low-speed networking protocols as well as high-speed ones?


Why should we need low speed network protocol?

- The objects connected in the context of the Internet of things are both **intelligent** and **non-intelligent**.
- Adapt to the low power nodes in the Internet of things
  - ✓ Low rate
  - ✓ Low communication radius
  - ✓ Low computational power, and low energy requirements
- The premise to operate on a wide variety of objects in the Internet of things is to connect them first, and low-speed network protocols are the premise to achieve **full connectivity**.

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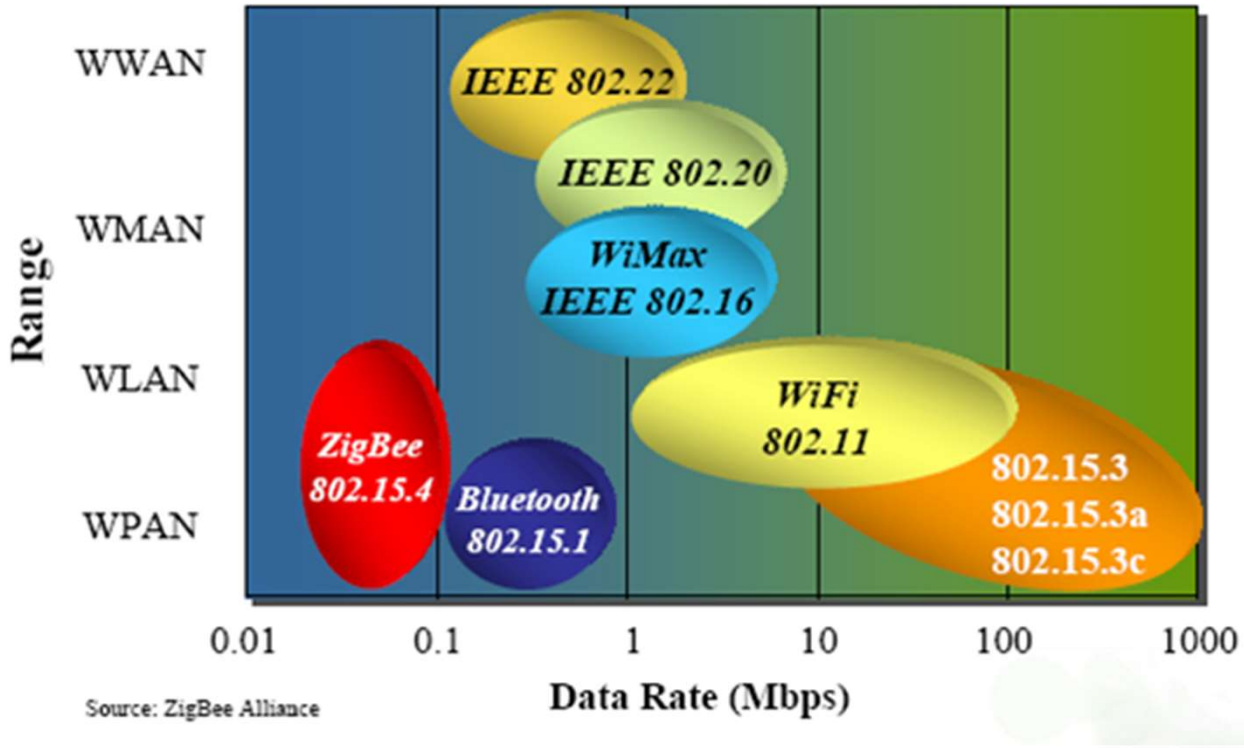
Why does the Internet of things need low-speed networking protocols as well as high-speed ones?

8.2 Wireless low speed network protocol

Typical wireless low speed network protocol:



- Bluetooth
- Infrared
- 802.15.4 / ZigBee

Bluetooth

Bluetooth technology is a short distance low power transmission protocol, which was first developed in 1994 by Ericsson of Sweden.

The frequency range adopted is 2.402 ghz-2.480 GHz.

Communication speeds typically reach around 1Mbps, and the new Bluetooth standard also supports speeds in excess of 20Mbps.
The communication radius varies from a few meters to about 100 meters.

The difference between Bluetooth and Wi-Fi

The positioning target of **Wi-Fi** is to replace wired devices in network applications, which can truly realize the transformation from wired to wireless. It can be used to transfer various files, video, audio, and realize various applications of the Internet.

Bluetooth is designed to replace the cables that individual users carry with their devices, such as headphones, keyboards, etc. These devices require relatively little bandwidth, or are not often used, for example to transfer small files between phones, or have relatively low resource ownership (power, computing resources, etc.).

Infrared

Infrared communication technology uses infrared ray to transmit data, which is an earlier wireless communication technology than Bluetooth technology.

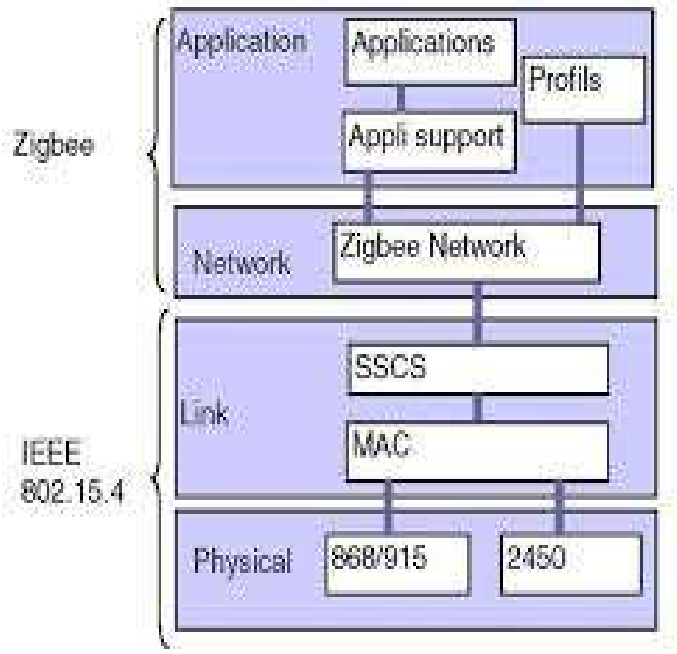
The characteristics:

- ✓ Infrared communication adopts light wave communication with wavelength of about 875nm, and the communication distance is generally about 1 meter.
- ✓ Small size, low cost, low power consumption, no need for frequency application and other advantages

Disadvantages

- ✓ Devices must be visible to each other
- ✓ The diffraction of obstacles is poor

802.15.4/ ZigBee



802.15.4 / ZigBee

It is the most famous wireless communication protocol **in the field of wireless sensor network**

- ZigBee mainly defines the specification of network layer, transport layer and application layer
- 802.15.4 mainly defines the physical layer and link layer specifications of short distance communication

802.15.4 Physical Layer

Frequency band: three frequency bands defined by the telecommunication standardization group of the international telecommunication union as open frequency bands for scientific research and medical treatment, including

- ✓ 868.0-868.6MHz, mainly used in Europe, single channel;
- ✓ 902-928mhz, North America, 10 channels, support to expand to 30;
- ✓ 2.4-2.4835GHz universal, 16 channels.

Transmission technology: the first is direct spread spectrum, later can be used frequency modulation, phase modulation and other technologies.

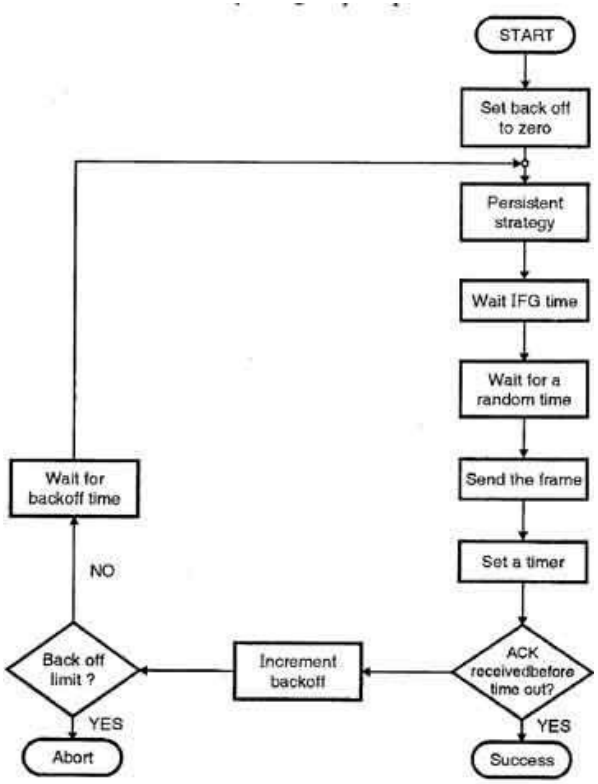
802.15.4 MAC

The media access control layer (MAC) controls and coordinates the nodes using physical layer channels

802.15.4 uses **CSMA/CA**, which is similar to 802.11 (Wi-Fi).

- ✓ Before transmission, firstly listen for whether there is any carrier using the same channel in the medium. If no carrier exists, the channel will be free, and then directly enter the data transmission state.
- ✓ If a carrier is detected by the system, the channel will be re-tested after a period of random withdrawal. The withdrawal time is specified by the specific protocol.

CSMA/CA Review



CSMA/CA procedure

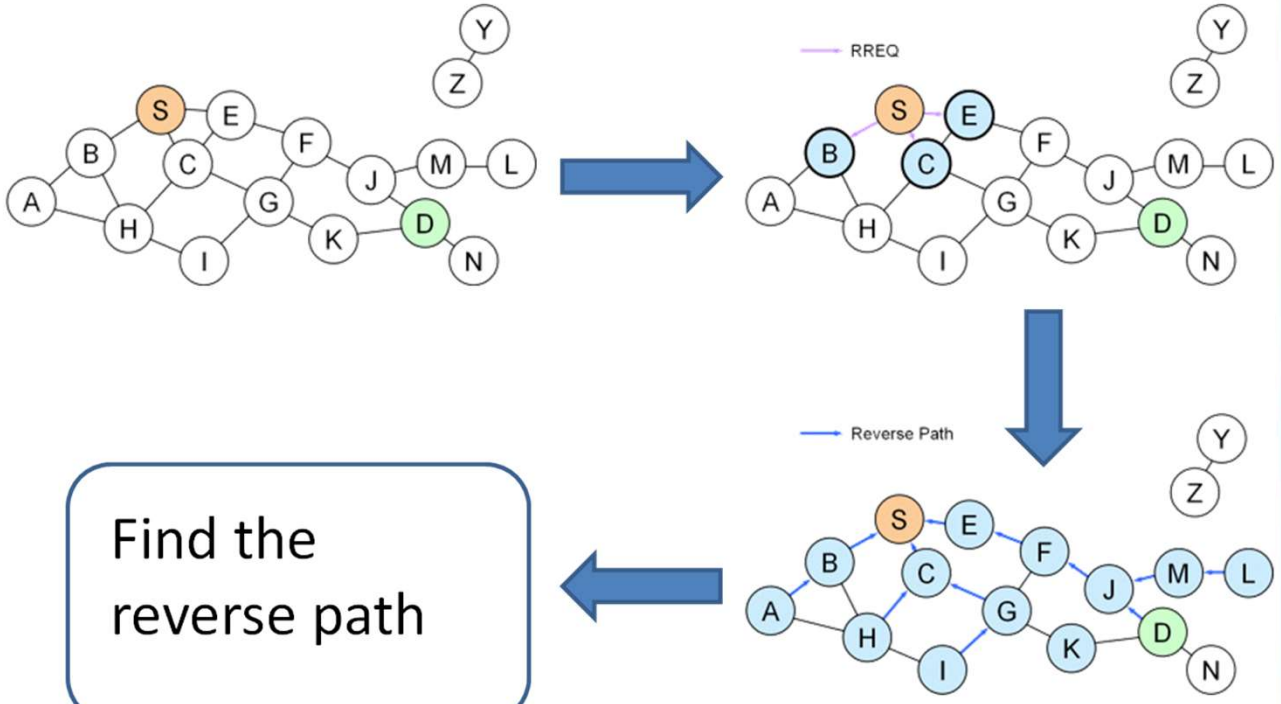
ZigBee Network Layer

Network layer functions: routing, discovery of new nodes and paths, determination of a node belonging to a subnetwork, etc.

ZigBee network layer adopts distance vector routing protocol (AODV)

- ✓ The source node broadcasts a routing request to all its neighbors
- ✓ After receiving the message, neighbor nodes broadcast the received message to their neighbors until the message reaches the destination node.
- ✓ When the destination node receives the routing request message, the destination node returns a routing reply to the source node.
- ✓ Replies are no longer broadcast to the source node, but instead follow the route of the routing request packet from the source node to the destination node, which allows the source node to send messages to the destination node.

AODV



Find the reverse path

ZigBee Above Network Layer

The network layer and above provide interfaces to end users

Similar to the Internet, above the network layer:

- Different types of transport services (such as TCP and UDP) need to be provided in the Internet model.
- There is also a need to provide a variety of applications based on different transport protocols (such as FTP, HTTP, etc.).

ZigBee and Common protocols

	ZigBee™ 802.15.4	Bluetooth™ 802.15.1	Wi-Fi™ 802.11b	GPRS/GSM 1XRTT/CDMA
Application Focus	Monitoring & Control	Cable Replacement	Web, Video, Email	WAN, Voice/Data
System Resource	4KB-32KB	250KB+	1MB+	16MB+
Battery Life(days)	100-1000+	1-7	.1-5	1-7
Nodes Per Network	255/65K+	7	30	1,000
Bandwidth (kbps)	20-250	720	11,000+	64-128
Range(meters)	1-75+	1-10+	1-100	1,000+
Key Attributes	Reliable, Low Power, Cost Effective	Cost, Convenience	Speed, Flexibility	Reach, Quality

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What problems should be paid attention to in the implementation of wireless sensor network protocol?

8.3 Wireless sensor network : Physical layer design

Link characteristics

- Dynamic property
- Asymmetric: links between two nodes are of good quality in one direction but very poor in the other.
- Spatial Correlation: because nodes with similar positions usually have similar environments.
- Temporal Correlation

The physical layer design should support 802.15.14 modules, such as CC2420, and meet the following requirements:

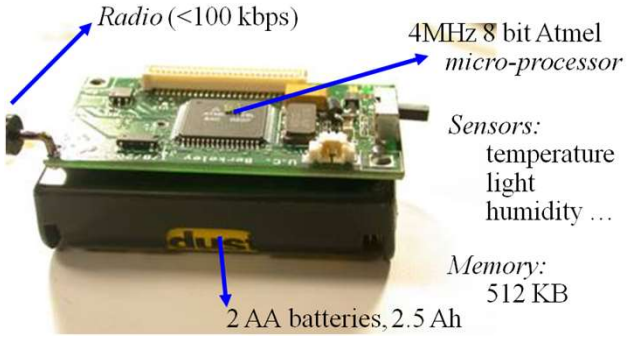
- Low energy consumption
- Low communication radius
- Low communication bandwidth

8.3 Wireless sensor network : MAC layer design

Wireless sensor network node particularity:

- Node function is small → calculation cannot be too complicated
- Node energy less - minimize unnecessary transmission
- Small communication range of nodes → multi-hop network design is required
- Node memory small → impossible to save all routing tables
- Node working environment complex → high adaptability protocol

MAC Layer：<u>Using CSMA/CA</u>



Wireless sensor network node

8.3 Wireless sensor network : MAC layer design

Wireless transceiver module occupies most power consumption!

Typical wireless sensor network node each module energy consumption		
Device	State	Electricity
CPU	active	1.8mA
	idle	54.5μA
flash	program	3mA
	erase	3mA
Wireless transceiver module	send	17.4mA
	Receive and monitor	19.7mA
	idle	21μA


MAC layer design: how to reduce energy consumption?

Radio transceiver usually works in three states (send, listen and idle), and the send and listen states are working, while the idle state wastes energy.

Low power listening protocol

- ✓ Sampling to listen
- ✓ Link layer scheduling

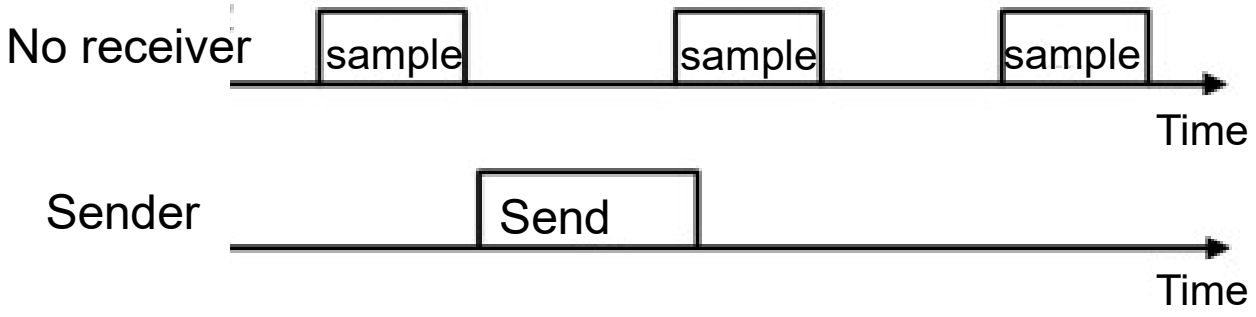
Sampling to listen

- ✓ The wireless transceiver module shuts down when there is no data
- ✓ Time sampling to obtain channel information

MAC layer design: Sampling and listening issues

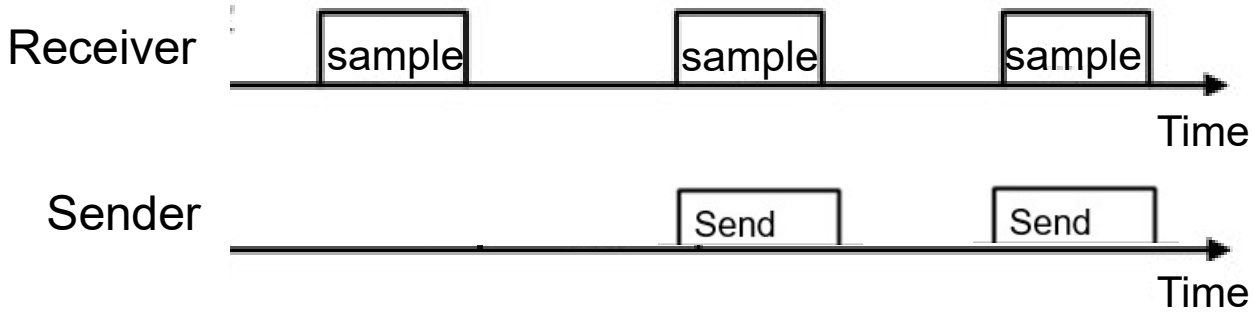
Assuming the sampling period is T, how can the sender ensure that the receiver can receive the data when sending it?

- ✓ By keeping the length of time the data is sent no less than T, the receiver is able to sample the data sent by the sender
- ✓ Then the receiver adjusts to receive state to receive data normally.



MAC layer design: Sampling and listening issues

There is still a problem: the sender most often needs to last a sampling period each time he sends, or it will cause unnecessary energy loss.
Better approach: synchronize sender and receiver to achieve higher efficiency → schedule




8.3 Wireless sensor network : MAC layer design

Main features:

- ✓ Links in wireless sensor networks are unreliable
- ✓ The limited functions and resources of wireless sensor nodes make it impossible for them to carry out complicated calculation, measurement and maintain huge routing tables.

Link quality becomes an important index that affects the performance of routing protocol. Link quality is considered in routing protocols of wireless sensor networks. **ETX** is a widely used path selection index, which can realize the typical link measurement method of wireless sensor network.

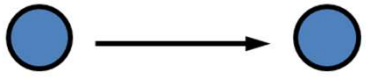
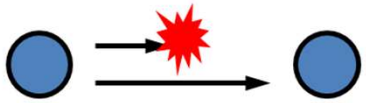
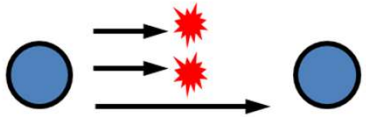
Two typical network layer routing protocols:

- ✓ Data collection protocol CTP
- ✓ Data distribution protocol Drip

ETX : Path selection index

ETX: (Expected Transmission Count), the total Transmission times required by successful Transmission of each package. The smaller ETX of a path represents the smallest total Transmission times caused by this path.

Link throughput ≈ 1/ Link ETX

Delivery Ratio		Link ETX	Throughput
100%		1	100%
50%		2	50%
33%		3	33%

ETX Calculation

- Assume that the links have ACKs and retransmissions

  P(TX success) = P(Data success) × P(ACK success)

  Link ETX = 1 / P(TX success)
  = 1 / [P(Data success) × P(ACK success)]

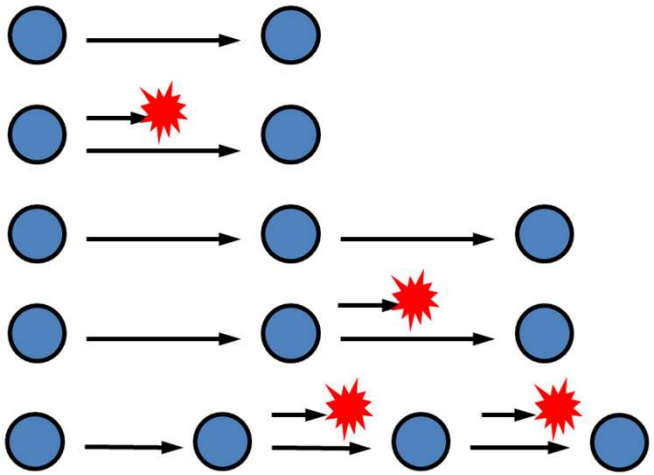
- Actually calculate ETX

  P(Data success) ≈ measured fwd delivery ratio r_{fwd}
  P(ACK success) ≈ measured rev delivery ratio r_{rev}
  Link ETX ≈ $1 / (r_{fwd} \times r_{rev})$

ETX Path

By minimizing transmission costs, ETX improves bandwidth utilization and effectively reduces sensor network energy consumption.
By measuring the quality of bidirectional links, ETX can effectively avoid asymmetric links.

Route ETX = Sum of link ETXs



Route ETX	Throughput
1	100%
2	50%
2	50%
3	33%
5	20%

Collection Tree Protocol

CTP (Collection Tree Protocol) is one of the widely used data Collection protocols, which can be implemented in TinyOS.

Basic process:

- ✓ Initialization stage: each node in the network broadcasts the ETX of its path to the sink node.
- ✓ After receiving the broadcast packet, each node dynamically selects the parent node according to the broadcast path ETX of the neighbor node, so as to minimize the ETX of its path to the sink node.
- ✓ After constant updating, each node in the network can choose a path to the minimum sum of ETX of sink node.

Basic features of CTP protocol

Link quality: synthesizes multifaceted information.

- ✓ Active switching control packet estimation + passive listening packet dynamic update
- ✓ Consider network layer queue overflow information to avoid congestion of nodes

Controlling packet sending: the use of trickles algorithm ADAPTS to control the frequency of sending packets, making the network unchanged and the number of packets sent very few; Once the network changes, quickly update the entire network.

- ✓ When the network is stable, the binary increases the packet sending interval to reduce the number of packets sent.
- ✓ In case of abnormal loop, shorten the transmission interval to the minimum, and make the network return to normal in time


Data distribution protocol

The data distribution protocol is used to reliably transmit packets to each node in the network. Drip protocol is widely used in wireless sensor network.

Basic working mode:

- Corresponds to a version number for each data item. The higher the version number, the newer the data.
- Each node periodically broadcasts version information of the data item
- When a Drip node finds that a neighbor has higher version information, it sends a request package to that neighbor.
- The node receiving the requested packet broadcasts the packet for the data item.

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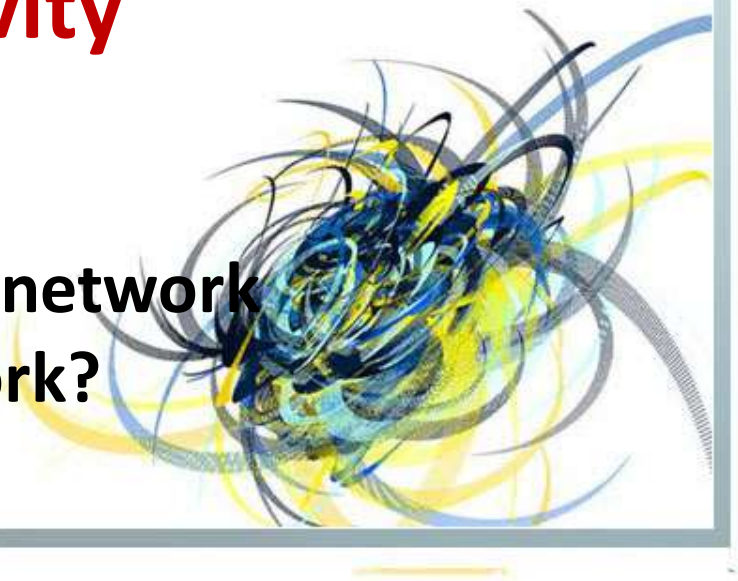


How does the wireless low speed network protocol fit into the IPv6 framework?

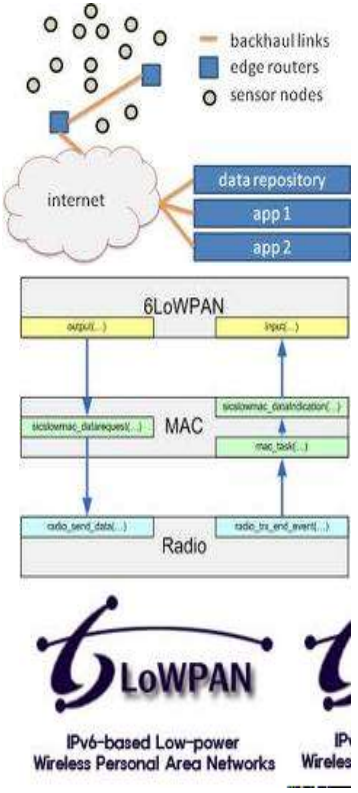
8.4 IPv6 Internet connectivity

IPv6 has been widely used in high-speed Internet protocols and is being gradually transplanted to low-speed network protocols.

6LoWPAN: interconnection protocol under the unified framework, connecting networks running IPv6 high-speed interconnection protocol and other networks running low speed protocol.

The challenge:

- ✓ Different transmission capacity challenges
- ✓ Different devices mark and identify challenges
- ✓ Different design goals challenge
- ✓ Different device management challenges



Conclusion

Review

This chapter introduces the typical wireless low-speed network protocol, mainly discusses the characteristics of each network layer of 802.15.4/ZigBee protocol, and discusses the problems that need to be paid attention to in the implementation of wireless sensor network protocol.

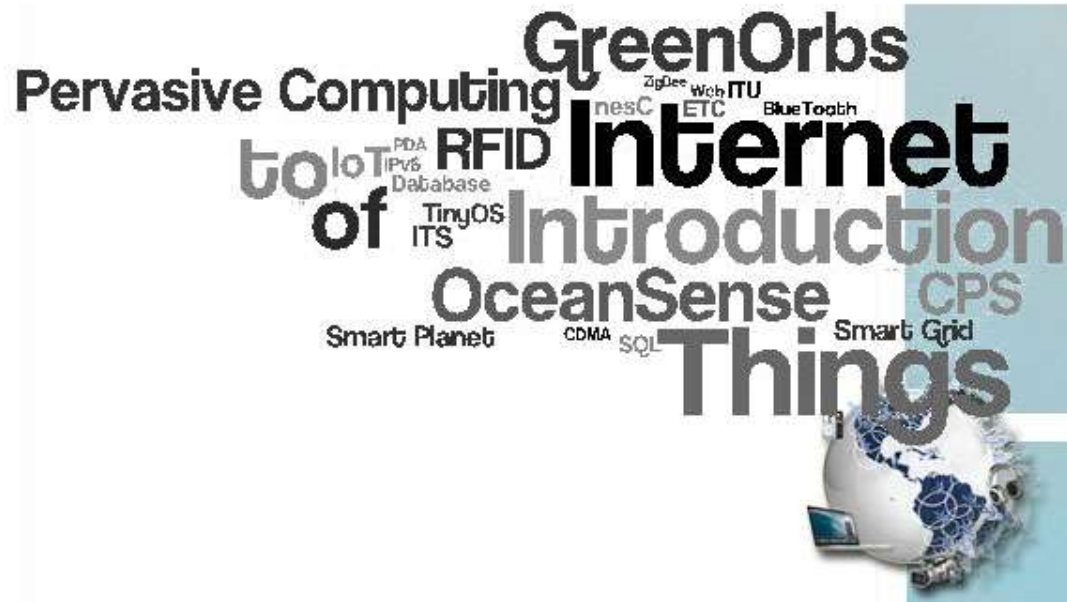
Key Points

- Understand why the Internet of things requires low speed network protocols.
- Compare wi-fi to understand the range and characteristics of bluetooth and infrared technologies.
- Understand the provisions of 802.15.4 for physical layer and link layer.
- Understand the principle of distance vector routing protocol.

Conclusion

Key Points

- Understand the link characteristics of physical layer and MAC layer of wireless sensor network.
- Master the low power listening protocol (sampling listening and scheduling) used by MAC layer to reduce power consumption.
- Understand the importance of link quality in network layer design of wireless sensor network.
- Grasp the principle and calculation of the link quality evaluation standard ETX.
- Understand typical routing protocols CTP and Drip of wireless sensor network layer.



Thank you!

Internet of Things