Z-Wave Tutorial

Z-wave technology based devices operates in ISM band. It is developed for low bandwidth data communication applications such as security sensors, home automation, alarms etc. The following section mentions frequencies used in z-wave. It uses 868.42 MHz in Europe and 908.42MHz in USA. Following table-1 mentions basic features of z-wave technology widely used in IoT(Internet of Things) due to low power and low data rate. Z-wave protocol is developed by Sigma Designs, Inc. including encryption. Open source implementation of Z-Wave protocol stack known as open-zwave is also available but it does not support security layer. Z-wave PHY and MAC layer specifications are defined in ITU-T G.9959 standard.

Specification	**z-wave support**
Standard	ITU-T G.9959 (PHY and MAC)
RF Frequency Range	868.42 MHz in Europe, 908.42 MHz in US
Data rate	9.6, 40, 100 Kbps
Maximum Nodes	232
Architecture	Master and slave in mesh mode
MAC layer	CSMA/CA
RF PHY modulation	FSK (for 9.6kbps and 40 kbps), GFSK with BT=0.6 (for 100 kbps)
Coding	Manchester(for 9.6kbps), NRZ(for 40 and 100 kbps)
Distance	30 meter in indoors, 100 meters in outdoors

Table-1: **z-wave features**

z-wave frequency bands

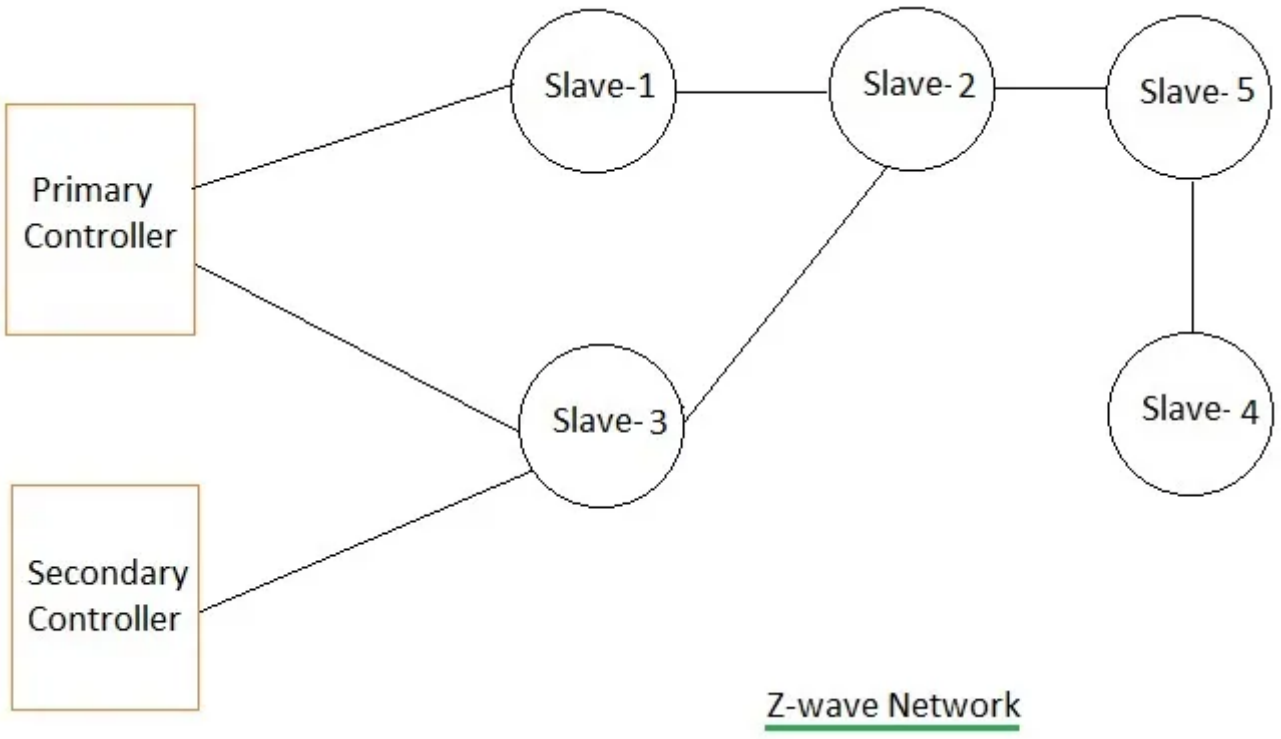
Following table mentions frequency bands, data rate and channel bandwidth supported by z-wave technology through out the world.

Region	**RF Center Frequency (G.9959/MHz)**	**Data Rate**	**Channel Width**
Australia	f_{ANZ1}/919.80,f_{ANZ2}/921.40,	100/ 40/9.6Kbps	400/ 300/300KHz

Brazil	Same as Australia		
Canada	Same as USA		
Chile	Same as USA		
China	f_{CN1}/868.40,	100/ 40/9.6Kbps	400/ 300/300KHz
European Union	f_{EU1}/869.85, f_{EU2}/868.40	100/ 40/9.6Kbps	400/ 300/300KHz
Hong Kong	f_{HK1}/919.80	100/ 40/9.6Kbps	400/ 300/300KHz
India	f_{IN1}/865.20	100/ 40/9.6Kbps	400/ 300/300KHz
Israel	f_{IL1}/916.00	100/ 40/9.6Kbps	400/ 300/300KHz
Japan	f_{JP1}/922.50, f_{JP2}/923.90,f_{JP3}/926.30	100/100/ 100 kbps for all bands	400/400/ 400 KHz for all bands
Korea	f_{KR1}/920.90,f_{KR2}/921.70,f_{KR3}/923.10	100/100/ 100 kbps for all bands	400/400/ 400 KHz for all bands
Malaysia	f_{MY1}/868.10	100/40/ 9.6Kbps	400/300/ 300KHz
Mexico	Same as USA		
New Zealand	Same as Australia		
Russia	f_{RU1}/869.00	100/40/ 9.6Kbps	400/300/ 300KHz
Singapore	Same as EU		
South Africa	Same as EU		
Taiwan	Same as Japan		
UAE	Same as EU		
USA	f_{US1}/916.00, f_{US2}/908.40	100/40/ 9.6Kbps	400/300/ 300KHz

Table-2: **z-wave frequency bands**

z-wave network



The **z-wave network** consists of controllers (one primary controller and more than one secondary controllers) and slaves. Controller devices are the nodes in a z-wave network which initiates control commands. It also sends out the commands to other nodes. The slave devices are the nodes which replies based on command received and also execute the commands. Slave nodes also forward the commands to other nodes in the network. This makes it possible for controller to establish communication with the nodes who are not in radio frequency region.

Controllers:
A controller device will have full routing table for this mesh network and it will host it. Hence controller can communicate with all the nodes of z-wave network. There are two types of controllers viz. primary and secondary.

The controller which creates new z-wave network initially will become primary controller. This primary controller is master controller in the network and there will be only one in each z-wave network. Primary controller will have capability to include and exclude the nodes in the network. Hence primary controller always keeps latest topology of the network. Primary controller also takes care of managing allocation of node IDs.

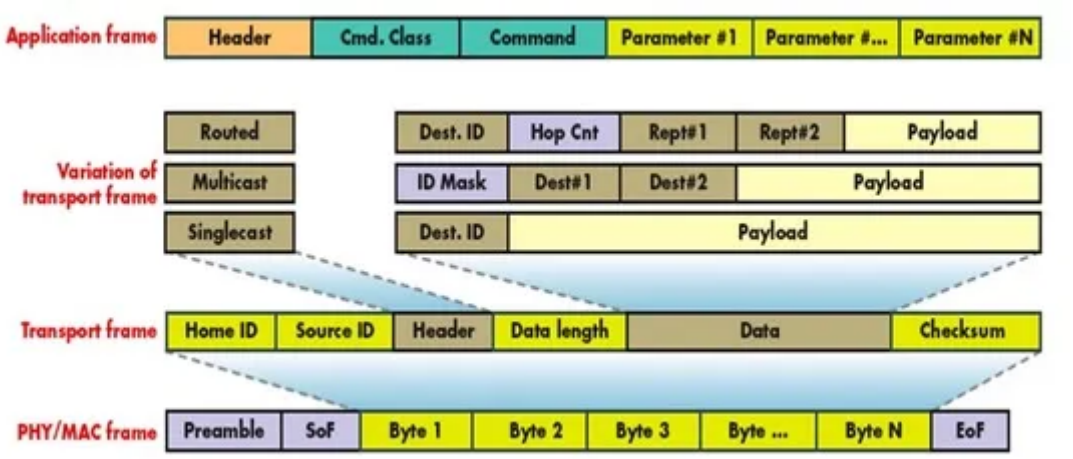
The controllers which are added to the z-wave network using the primary controller are known as secondary controllers. They do not have capability to include or exclude any nodes. They will get copies of the routing tables from primary controller.

Slaves:
The slave devices/nodes in z-wave network receive the commands and performs action based on the commands. These slave nodes are unable to transmit information directly to the other slave nodes or controllers unless they are instructed to do so in the commands. The slave nodes do not compute routing tables. They can store routing tables. They will act as a repeater.

Home ID:
The z-wave protocol uses Home ID field to separate the networks from each other. It is 32 bit unique identifier which will be pre-programmed in all the controller devices. At the start, all the slave nodes will have Home ID value as zero. All the slave devices need Home ID value in order to communicate in the z-wave network. This will be communicated to all by the controller. Controllers exchange Home ID which makes it possible for more than one controller to control slave nodes.

Node ID:
This node ID is 8 bit value. Similar to Home ID, they are also assigned to slave nodes by controller. Node ID's are used in order to address individual nodes in a z-wave network. These Node ID's are unique within a network defined by a unique Home ID.

z-wave frame structure



As shown in the fig-1, **z-wave frame** consists of a preamble part, SOF(Start of Frame), Frame data and EOF(End of Frame) symbol. The data part is manchester codes or NRZ coded based on data rate. MAC layer controls the RF spectrum. Data part comes from the upper layers and z-wave frame as mentioned in formed at the MAC/PHY layers. After this is done the z-wave frame as depicted is transmitted by the RF antenna after necessary radio frequency conversion as desired using RF Transceiver.

z-wave protocol stack

The **z-wave protocol stack** consists of PHY layer, MAC layer, Transport layer, Network layer and application layer. Other than servicing their peers all the layers have their own tasks.

z-wave Physical layer(z-wave PHY)

The **z-wave Physical layer** takes care of preamble insertion in the z-wave frame. It takes care of modulation and demodulation as well as RF channel selection. It takes care of data frame transmission and reception.

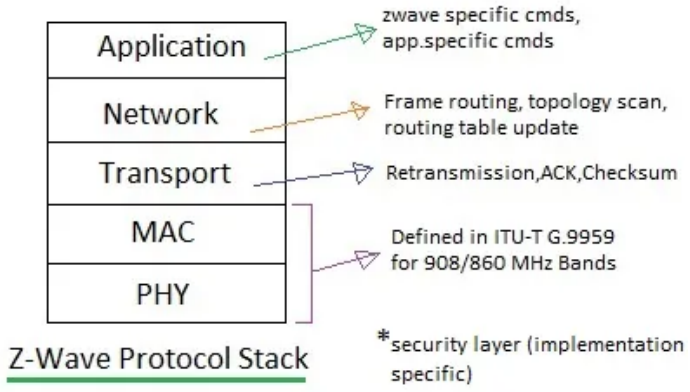
z-wave security

As z-wave open protocol architecture does not specify security layer specifications it is implementation specific. z-wave security layer provides secured communication between nodes as well as between controllers and nodes.

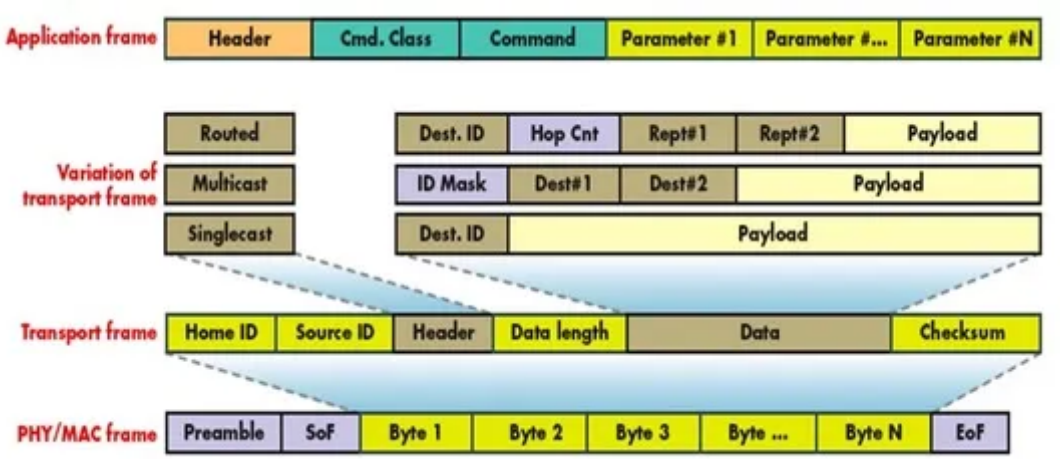
z-wave Protocol Stack

The z-wave protocol layers main function is to communicate very short messages of few bytes long from a control unit to one or more z-wave nodes. It is a low bandwidth and half duplex protocol to establish reliable wireless communication. z-wave protocol stack need not have to take care of large amount of data as well as any kind of time critical or streaming data.

As shown in the fig-1, z-wave protocol stack consists of 5 layers viz. PHY layer, MAC layer, Transport layer, network layer and application layer. The security layer is not defined in z-wave open protocol specifications and hence it is implementation specific. Following are the major functions of these protocol layers.
➤Physical layer takes care of modulation and RF channel assignment as well preamble addition at the transmitter and synchronization at the receiver using preamble.
➤MAC layer takes care of HomeID and NodeID, controls the medium between nodes based on collision avoidance algorithm and backoff algorithm.
➤Transport layer takes care of transmission and reception of frames, takes care of retransmission, ACK frame transmission and insertion of checksum.
➤Network layer takes care of frame routing, topology scan and routing table updates.
➤Application layer takes care of control of payloads in the frames received or to be transmitted.



The fig-2 depicts fields at various protocol layers of z-wave stack. The figure mentions PHY/MAC frame, 4 types of frames at transport layer and application layer frame. Before we move to understand different protocol layers go through the concept of z-wave network in z-wave tutorial (http://www.rfwireless-world.com/Tutorials/z-wave-tutorial.html) page.



z-wave Physical Layer

The physical layer in z-wave does many functions. The important ones are modulation and coding as well as insertion of known pattern(‘preamble’) used for synchronization at receiver. It also takes care of RF channel allocation as desired. The input for configuring the z-wave PHY is data rate (9.6 or 40 or 100 Kbps).

z-wave MAC Layer

MAC layer as the name suggests takes care of medium access control among slave nodes based on collision avoidance and backoff algorithms. It takes care of network operation based on HomeID, NodeID and other parameters in the z-wave frame.

z-wave Transport Layer

Z-Wave transport layer is mainly responsible for retransmission, packet acknowledgment, waking up low power network nodes and packet origin authentication. The **z-wave transport layer** (or transfer layer) consists of four basic frame types. These are used for transferring commands in the network. All the frames use the format as mentioned below.

Transport Frame = { HomeID, Source NodeID, Header, length, Data byte(0 to X), Checksum }

The 4 frame types of transport layer is explained below:

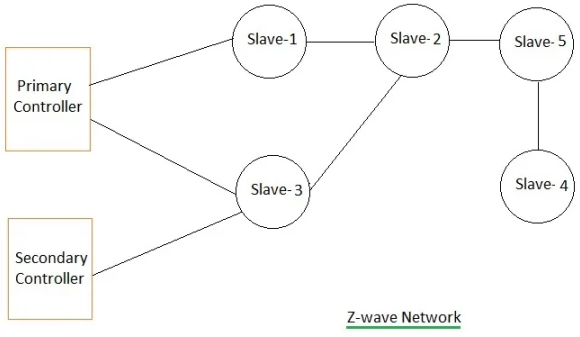
Singlecast frame type:
These type of frames are transmitted to one specific z-wave node. The frame is acknowledged so that transmitter will know whether the frame is received or not. If this frame or its ACK is lost or damaged than the singlecast frame is retransmitted.

ACK frame type:
It is singlecast frame where in data payload part does not exist. This is explained above.

Multicast frame type:
These frames are transmitted to more than one node i.e. max. of 232 nodes. This type of frame does not support acknowledgement concept. Hence this type is not used for reliable communication.

Broadcast frame type:
These frames are received by all the nodes in a network and they are not ACKed by any nodes.

z-wave Network Layer



Z-wave Network

This z-wave network layer controls the frame routing from one node to the other node. Both the controllers as well as slave nodes participate in frame routing. The **z-wave network layer** is responsible for the following tasks:

• Transmission of a frame with correct repeater list
• Scanning of network topology
• maintenance of routing table in the controller

This z-wave routing layer consists of two kinds of frames. These are used when repeatition of frames become necessary.
Routed Singlecast Frame Type:
It is a one node destination frame with acknowledgement which contains repeater information. The frame is repeated from one repeater to another until it reaches the desired destination.

Routed Acknowledge Frame Type:
This acknowledgement frame is a routed singlecast frame without payload. This will inform the controller that the routed singlecast frame has reached the desired destination.

	1	**2**	**3**	**4**	**5**	**6**
1	0	1	1	0	0	0

2	1	0	0	0	1	0
3	1	1	0	0	0	0
4	0	0	0	0	1	0
5	0	1	0	1	0	0
6	0	0	0	0	0	0

Table-1: z-wave routing table

Controller maintains the routing table. This table contains information about all the nodes in the network. This routing table is a bit field table as shown in the table-1. This routing table is built by primary controller based on information received from all the nodes in the z-wave network.

z-wave Application Layer

This layer is responsible for decoding and execution of commands in a z-wave network. The frame format used in **application layer** consists of following fields.

Frame Format = { Single/Multi,broadcast frame header,
Application command class,
Application command,
Command parameter1-to-X

The application command class defines class of commands the command belong to:
00h-1Fh (This command class reserved for Z-wave protocol)
20h-FFh (This command class reserved for Z-wave application)
All the z-wave frame types except the acknowledgement frame contain an application command.