Application Note

Z-Wave Reliability Application Note

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1 INTRODUCTION

1.1 Purpose

The purpose of this Application Note is to describe the reliability of a Z-Wave network based on ZM1220 Z-Wave Modules.

1.2 Audience and prerequisites

The Application Note is targeted the reader having basic knowledge of the Z-Wave Technology.

Datasheet

Z-Wave Network Reliability

Z-Wave Reliability

Many traditional RF systems are considered to be unreliable due to the characteristics of radio waves, such as reflection, diffraction and scattering causing RF fading effects. The Z-Wave protocol has overcome these challenges and is highly reliable due to frame acknowledgment, frame checksum check, retransmission, collision avoidance and sophisticated routing mechanism.

Zensys has developed a range of modules containing a Z-Wave Single Chip (ZW0102) and RF circuitry enabling easy integration of RF based control circuitry into OEM products. These modules are in general called Z-Wave Modules. This document will describe the reliability of the communication in a network based on these ZW0102 Z-Wave Modules.

Selecting a reliability metric

Often RF component suppliers/developers lists their reliability in Bit-Error-Rate (BER) or in Frame-Error-Rate (FER). BER is the number of lost bits transmitted and FER is the number of lost frames transmitted. These metrics, however, are not very well suited for expressing the reliability of a two-way communication system as Z-Wave. Zensys therefore uses the metric Communication Error Rate (CER) to express the reliability as experienced by the application developer and end-user.

A CER is an expression of how often a Z-Wave Command is lost. A Z-Wave Command consists of both a “Command”-frame sent by the controlling node and an “Acknowledge”-frame replied by the controlled node, i.e. a two-way communication. A Z-Wave frame is typically 20bytes (160 bits) in length. The Z-Wave Module [1] has a CER better than 10^{-6} for a point-to-point system and a CER of 10^{-8} (for uncorrelated errors) for larger Z-Wave Networks using routing.

The low CER in a point-to-point system (only one controller and one node in a system) is achieved by frame acknowledgement, frame checksum check, retransmission (two retries) and a back-off algorithm supported by the Z-Wave protocol. When implementing a larger Z-Wave Network the Z-Wave Protocol uses a routing protocol (patent pending), which tries several other communication routes if the first selected route is failing.

When listing the BER/FER in datasheets etc. it is often for an ideal system meaning no other external RF interferences or reflections (open air). The following two chapters describe real life CER measurements of both a Point-to-Point network as well as larger Z-Wave networks to prove the reliability of the Z-Wave network.

Z-Wave Protocol

As a part of the Z-Wave Protocol several features have been implemented in order to improve the reliability of the RF communication. These features are:

1. Collision Avoidance
2. Back off algorithm
3. Frame Acknowledgment
4. Frame Checksum Check
5. Retransmission
6. Sophisticated routing

Collision Avoidance

The MAC Layer has a collision avoidance mechanism that prevents Z-Wave nodes from starting to transmit while other nodes are transmitting. Collision avoidance is achieved by having the Z-Wave nodes listen before transmitting. If other Z-Wave nodes are transmitting, the node will delay its transmission.

Back off algorithm

If two frames are transmitted simultaneously a collision happens. The transmitters detect the collision, as they don't receive any acknowledgment frame. In order to reduce the possibility of yet another simultaneously transmission the MAC layer has a back off algorithm, which inserts a random delay before the frame is retransmitted.

Frame Acknowledgment

To assure correct reception of a Z-Wave frame the receiving node replies an Acknowledgement frame to the sending node if the frame has been correctly received (error free).

An Acknowledgement frame is only replied on Singlecast frames, not Multicast and Broadcast frames [5].

Frame Checksum Check

All Z-Wave frame types contain an 8-bit non-correcting error check field. The checksum is calculated on the whole frame except the first bytes containing the HomeID address [2].

If the receiving node encounters a checksum error it will not reply an Acknowledgment frame to the transmitting node. The transmitting node will automatically retransmit the frame.

Retransmission

All received Z-Wave Single cast frames will be replied with an acknowledgement frame to the transmitter to assure correct frame reception. If the acknowledgement frame is lost or corrupted the transmitting node will automatically retransmit the frame after a timeout period has expired. In order to avoid potential collisions with parallel systems, the retransmission is delayed in a random delay determined by the Back off algorithm.

All nodes will execute two retransmissions if necessary, i.e. a total of three attempts will be executed.

Routing

The patented routing protocol ensures an even more reliable network than in a traditional point-to-point network due to the increase in the number of retries using different routes. The more Z-Wave nodes in a system the more routes can be used to reach the node to be controlled.

When the network contains multiple nodes of which some are used as repeaters the controller waits for acknowledgement from the Repeater node but it also waits for a route acknowledgement telling it that the frame arrived to the final destination as shown in Figure 1.

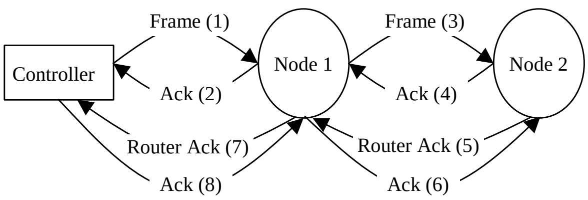

Figure 1 Frame flow

Node 1 is the repeating node.

Multiple Routes

In the example shown in Figure 2 the network consists of multiple nodes making it possible to use different routes if the communication fails. The Controller has multiple "Start Nodes" (3 in the shown example), which can all be used as the first node in the route. Starting through Start Node 1 it tries two different routes. If both routes fails it tries two additional routes via Start Node 2. If these also fail, again two additional routes are tried via Start Node 3. If all six routes fail (could be the receiving node is switched off) an error message will be generated by the protocol and is presented to the Application Layer.

The above mentioned protocol implementations describes how the Z-Wave protocol improves the reliability of a RF based network. In conjunction with the protocol a robust RF circuitry must be implemented in order to achieve the optimum performance of the Z-Wave network. The following sections describe a range of real life tests performed with the ZM1220 Z-Wave Module developed by Zensys A/S. These tests prove the reliability of the Z-Wave protocol in combination with the well-tested and proven ZM1220 Z-Wave Modules.

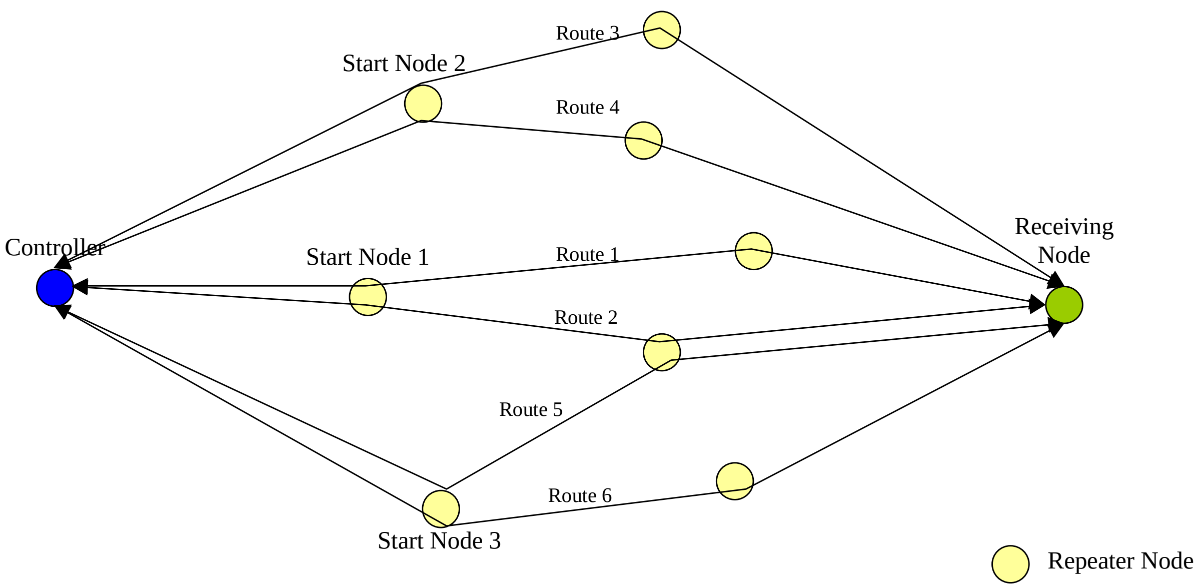

Figure 2 Routing setup with 10 nodes and 1 controller

Real Life Tests

Test Equipment

All the tests have been performed with ZM1220 Z-Wave Modules [1] mounted either on a Development Module [3] or an Interface Module [4].

A ZM1220 Z-Wave Module mounted on a Development Module connected to a Laptop is used as “Tester”. The Laptop contains test SW to transmit frames to one or several nodes and count the number of successfully transmitted/ received frames (CER). The “Tester” is used in all tests described in the following.

In order to get a picture of the RF performance of the Z-Wave Modules the “Tester” does *not* use re-transmission.

The Z-Wave Modules under test (DUT) is mounted on an Interface Module.

The output power of the Z-Wave Modules used is adjusted to comply with FCC Part 15 requirements.

Point-to-Point Reliability

A point-to-point network consists of only two Z-Wave nodes. Three different point-to-point tests have been performed for with the ZM1220 Z-Wave Module as described in the following.

Temperature Test

The purpose of the temperature test is to verify that the ZM1220 Z-Wave Module [1] can operate successfully even beyond the temperature limits specified for the Z-Wave Module.

The Z-Wave Module is specified to operate in the temperature range 0°C to 85°C. The Z-Wave Module was tested at the following temperatures:

- -10°C
- 25°C
- 75°C
- 95°C

At each temperature the Z-Wave Module is tested for minimum 12 hours.

Test set-up:

In order to eliminate errors caused by RF interferences the PCB antennas are disconnected at PCB level on the two Z-Wave Modules (the “Tester” and the DUT) and the RF circuitries are connected to each other via a coax cable. The DUT is inserted into a temperature chamber. The “Tester” transmits 1,000,000 frames.

Test Result:

The result listed in the table below is *without* retransmission.

Temperature Test	
Temp.	Communication Error Rate without retransmission
-10°C	$1.4{\cdot}10^{-5}$
25°C	$3.7{\cdot}10^{-5}$
75°C	$1.9{\cdot}10^{-5}$
95°C	$2.9{\cdot}10^{-4}$

Table 1 Four-corner test result

The listed CER is *without* retransmission meaning that the real CER for the Point-to-Point system with retransmission is significantly below 10^{-6}, see appendix A for calculation.

Automatic Point-to-Point Test

The purpose of the automatic Point-to-Point test is to verify the CER in a real-life environment with a distance between two nodes (“Tester” and DUT) of 10, 20, 30 meters respectively.

Test Setup

Three Z-Wave Modules are each implemented on an Interface Module [4]. The three Z-Wave Modules are located in an unobstructed environment (large unobstructed room) at distance of 10, 20 and 30 meters from the “Tester”.

The “Tester” transmits commands to the Z-Wave Modules individually *without* the use of retransmission and routing.

Test Result:

520,000 frames have been transmitted to each of the three Z-Wave Modules.

Distance	*Lost frames*	*CER without retransmission*
10 Meters	1	$1.9*10^{-6}$
20 Meters	5	$9.6*10^{-6}$
30 Meters	8	$1.5*10^{-5}$

Table 2 Automatic Point-to-Point Test

The listed CER is *without* retransmission meaning that the real CER for the Point-to-Point system with retransmission is significant below 10^{-6}.

Variable Distance Point-to-point Test

Due to the physical nature of RF waves fading effects occur when the RF waves reflects on objects like walls, floors, doors, tables etc. The fading effects are experienced as "RF-holes" with poor communication. The "RF-holes" typically disappears when moving one of the nodes a few centimetres.

The purpose of the variable distance Point-to-Point test is to verify the CER at various distances between the "Tester" and four different Z-Wave Modules in order to locate and illustrate the effects of RF-fading.

Test Setup

The four Z-Wave Modules are all implemented on an Interface Module located 1 meter above the ground and 0.4 meters apart from each other. The "Tester" transmits 100 commands to each DUT and counts the successfully transmitted commands.

At 5-meter intervals the "Tester" is positioned in four different locations in a radius of 30cm.'s from the centre of the interval, i.e. giving 400 sent frames for each interval. The test area is a large unobstructed room from 0 to 35 meters where as from 35 – 45 meters (maximum distance) is in a small room next to the large room accessed through a 120cm wide door. The "Tester" and the Z-Wave Modules are always in-line-of-sight.

Test result

The numbers listed in the table in appendix A are the CER without retransmission for the four measurements at each 5-meter interval.

The graph shown in Figure 3 shows the theoretically calculated CER (with retransmission) based on the numbers listed in appendix A.

As seen with increased range the natural signal path loss and the RF fading effects caused by reflections etc. begins to show as increased CER.

The CER is improved dramatically when a Z-Wave Network consists of more nodes using the routing capabilities.

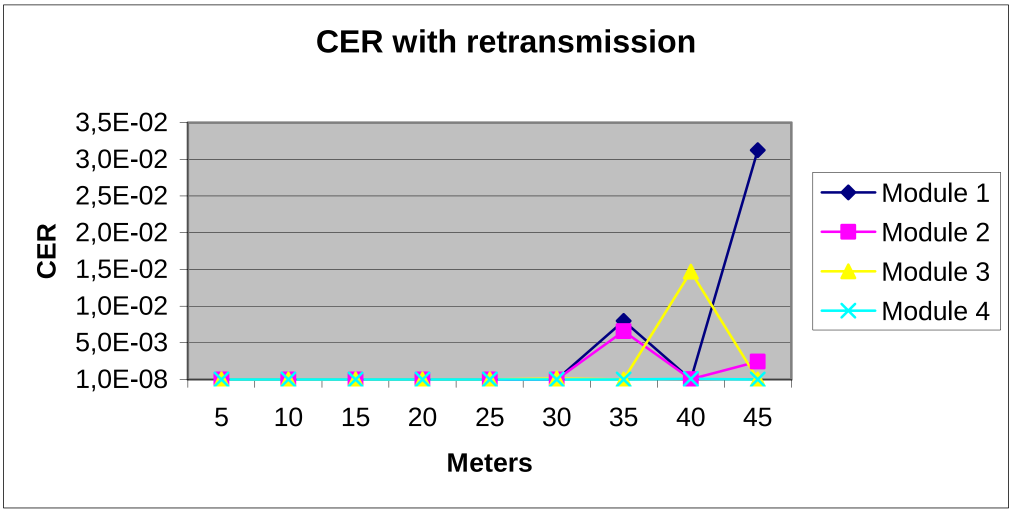

Figure 3 Theoretical calculated CER with retransmission

Z-Wave Network Reliability

The tests mentioned in the previous sections have been made with Point-to-Point systems not using retransmission and routing. To overcome the fading effects previously described retransmission and routing has been implemented as a part of the Z-Wave Protocol.

Z-Wave Network Reliability Test

The purpose of this test is to verify the reliability of a Z-Wave Network where retransmission and routing is taking place.

Test Setup

Fifteen Z-Wave Modules implemented on Interface Modules were evenly distributed across an approximately 1000m^2 obstructed office building with walls, doors and windows (see Figure 4). The “Tester”, i.e. the Controller Node constantly transmits “light-on”/”light-off” commands to Slave Node individually using retransmission and routing.

Test Result

A total of 1,500,000 commands were sent and *no* commands were lost. With the 1,500,000 commands executed the CER for the system is theoretically better than $6.7 \cdot 10^{-7}$.

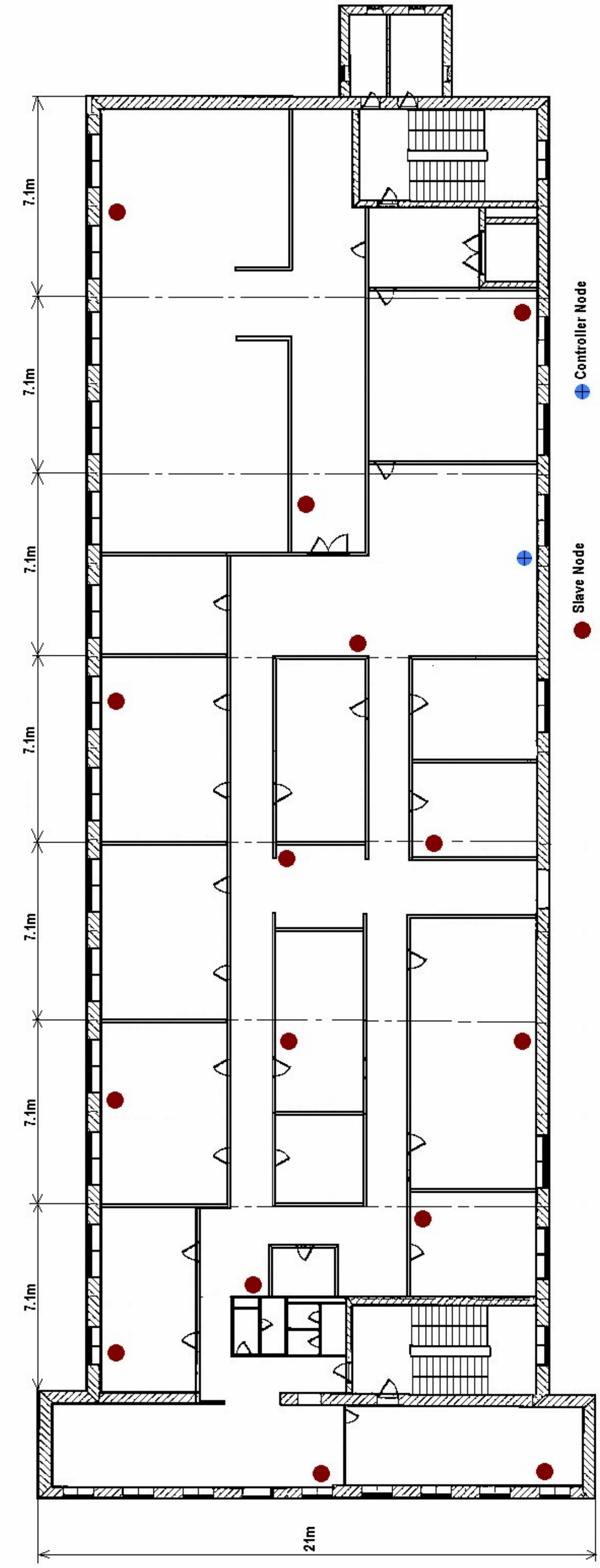

Figure 4 Z-Wave Network Reliability Test Setup

APPENDIX A

The table below shows the lost commands out of 100 transmitted as described in the “Variable Distance Point-to-point Test” section. As seen the fading effects begins to show a 30 meters and upwards. The CER is without the use of retransmission.

	CER without retransmission and routing							
Range	1		2		3		4	
5	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
20	0	0	1	0	0	0	0	0
	0	0	0	0	0	0	2	0
25	0	0	0	0	0	2	0	4
	5	0	0	0	1	0	0	4
30	0	0	3	0	0	21	0	0
	0	0	0	0	0	0	0	0
35	0	0	0	75	0	0	0	0
	0	80	0	0	0	0	0	0
40	2	8	0	8	0	6	0	17
	0	0	0	3	0	92	0	0
45	76	21	23	10	6	0	4	0
	29	0	0	21	0	0	0	0

Notes:

1. The CER numbers are without retransmission.
2. The RF output power of the Z-Wave Modules and the “Tester” used is adjusted to comply with the FCC requirements (-3dBm). Note that in EU the output power may be adjusted to maximum output power of the Z-Wave Single Chip (+5dBm) according to regulations.

The CER listed in the table above is without retransmission (and routing) the CER using retransmission is theoretically calculated with the following equation (only valid for uncorrelated errors):

$$CER_{withretransmission} = \left(\frac{Number\ of\ lost\ frames}{Number\ of\ transmitted\ frames} \right)^3$$

As example the theoretical calculated CER for Z-Wave Module at 40 meters are:

$$CER_{withretransmission} = \left(\frac{2+8}{400} \right)^3 = 6.25 \cdot 10^{-4}$$

2 REFERENCES

Always refer to latest revision of the document.

[1] Zensys, DSH10033, Datasheet, ZM1220 Z-Wave Module
[2] Zensys, INS10244, Instruction, Z-Wave Node Type Overview and Network Installation Guide
[3] Zensys, DSH10087, Datasheet, ZW0102 Z-Wave Development Module
[4] Zensys, DSH10086, Datasheet, ZW0102 Z-Wave Interface Module
[5] Zensys, SDS10243, Software Design Specification, Z-Wave Protocol Overview