Texas Instruments

Technical Brief
SPRT734–November 2017

Network Algorithms for LPWAN

Ben Gilboa

ABSTRACT

Low Power Wide Area Network (LPWAN) refers to wireless IoT networks that connect "things" like sensors at low bit rate, long range and low power. The Sub-1 GHz ISM band (around 915 MHz in US and 868 MHz in EU) is a common radio frequency that is used for such LPWAN physical layer. For the MAC layer different technologies use different network algorithms. This technical brief explains the main considerations when designing or choosing a technology based on its MAC layer properties and uses an example of building security system to give better idea of the discussed tradeoffs. It explains how to examine an efficient network algorithm and compares the CSMA/CA and the ALOHA network algorithms that are two common networking algorithms for LPWAN.

Contents

List of Figures

Trademarks

All trademarks are the property of their respective owners.

1 Building Security System Use-Cases

To better relate and understand how the networking algorithm of a wireless network system may impact the performance in different use-cases, building security use-cases are used as an example.

Consider a security system in a typical building or a large house. It is constructed from several sensors as end nodes that are connected to main control. The sensor nodes are door and window sensors, motion detectors, glass break detectors, an so forth. It may also include door keypad, electronic lock, people counting devices and more. The system may have 100s of nodes and different type of nodes that may have different communication requirements. All nodes in the system need to be securely connected to main control to allow observability and controllability of the entire system. The system designer may design the system to support all type of different features that imply different requirements from the wireless network standpoint. For example, all connected nodes check in periodically and update their status even without a specific status change – this requirement sets a constant amount of uplink traffic. Another example, all nodes are capable of having their software updated over the air – this requirement mandates significant amount of reliable downlink bandwidth.

Copyright © 2017, Texas Instruments Incorporated

In addition, the network has to meet certain latency for mission critical messages both for uplink and downlink. For example, a window sensor that indicates an intrusion must be able to send its indication as fast as possible. Electronic lock that needs to be opened from remote by the main control when someone is standing in front of the door must be able to send and receive data in short latency.

2 What is a Network Algorithm?

A network algorithm is a method in which devices in the network access the medium for transmitting their messages. It defines the conditions under which devices are allowed to transmit. Similar to a group of people trying to conduct a conversation, there are some rules that they all must follow so the communication is effective. For example, when one person speaks, the rest don't speak. There are rules that are set by the network algorithm to assure effective communication and fairness in the network so all nodes get uniform chance to deliver their messages.

Network algorithm can be coordinated or multiple accesses:

Coordinated network: one central device manages the network and gives permissions to nodes to transmit according to a defined order and time schedule.

Uncoordinated or multiple access network: all nodes (and central device) that participate in the network are allowed to transmit whenever they chose according to some set of rules that are defined in the algorithm. This document focuses on uncoordinated networks.

3 Importance of Network Algorithm

With the evolution of the IoT, networks are getting larger and use-cases becoming more complex. For example, smart meters or smart cities networks contain 100s if not 1000s of nodes. Cloud connectivity, over the air software upgrades, security and other system use-cases mandate more complex two ways communication and lower latency. In addition, more and more devices are being connected every day and more networks are being deployed while the medium remains the same. Therefore, an efficient network algorithm is required in order to achieve performance and network scalability over time.

OEMs who are developing their own network protocol or evaluating different existing networking solutions should consider the network algorithm in light of their use-case. Some examples for common network aspects that need to be considered:

- Network size, expected throughput and range
- Are the nodes expected to be battery operated or not?
- Does the use-case target mainly for uplink (from nodes to central hub or cloud) or downlink (from central hub to nodes) communication?
- What is the expected latency in the network
- Can packet delivery fail? Is it essential that every packet reaches its destination eventually or is it ok that some messages are dropped?
- What are the required security measures in the network?

4 Efficient Network Algorithm Properties

The following parameters are useful when evaluating the performance of a network:

- Theoretical channel capacity – How much data can be delivered in the channel assuming perfect usage of the channel for given technology. Bit-rate, packet overheads such as headers and CRC, acknowledgments, and protocol defined spacing between frames are all considered. However, it assumes no channel "waste". No idle time or any packet error is assumed when calculating the theoretical channel capacity
- Channel load - The "demand" from the channel. This is a combination of the number of nodes and the amount of data each node needs to transmit in a certain use-case. It is measured in percentage of the theoretical channel capacity and may be over 100% if all nodes combined are trying to transmit more than the theoretical channel capacity.

Copyright © 2017, Texas Instruments Incorporated

- Channel utilization - The actual amount of data that is delivered by the network in a given time compared to the theoretical channel capacity. When 2 packets collide or when packet transmission is delayed the channel utilization drops. This is the metric that is used to examine the performance of the networking algorithm

  An optimal network channel utilization follows Equation 1.

$$Channel\ Utilization = \begin{cases} Channel\ Load\ for\ Channel\ Load < 100\% \\ 100\% \qquad for\ Channel\ Load > 100\% \end{cases} \tag{1}$$

  As illustrated in Figure 1, as long as the load is below 100%, the optimal network is able to deliver the load. Once load reaches 100%, the optimal network maintains 100% channel utilization.

  The dynamic range is where the network can scale and grow. The more nodes are trying to deliver, the more is being delivered in 1:1 ratio. Network deployments should target to operate in the dynamic range. Saturation range is where the network is too small to meet the demand. The requirement from a robust network is to maintain and deliver as much as possible (ideally its 100%). If the utilization drops significantly when the load increases above 100%, then the network might fail in case of a sudden or temporary overload.

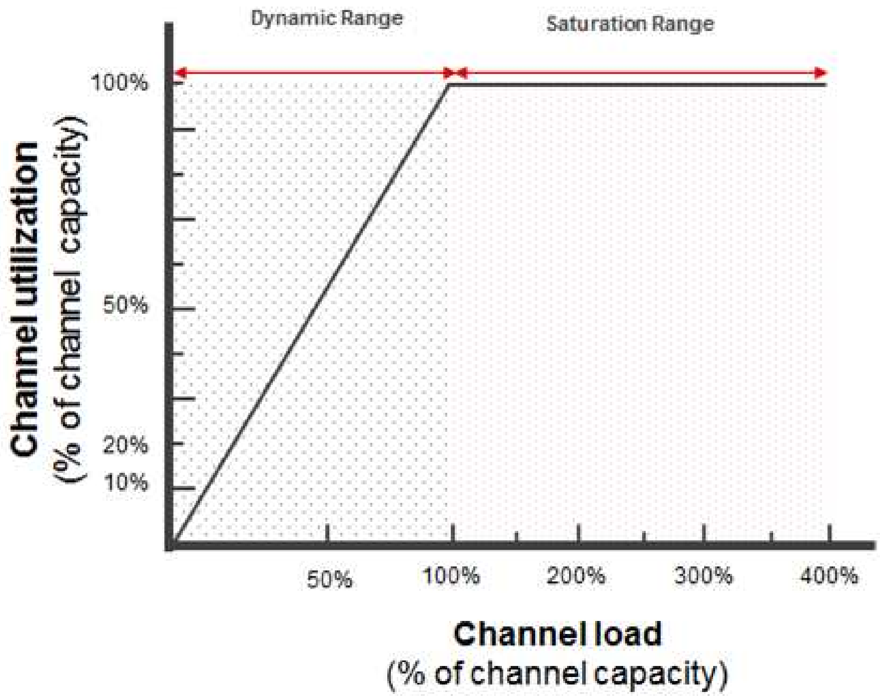

Figure 1. Optimal Network Performance

Copyright © 2017, Texas Instruments Incorporated

5 ALOHA Network Algorithm

ALOHA algorithm invented for computer networking in Hawaii during the early 70s. The main advantage of the ALOHA algorithm is its simplicity. A node that has information to send does the following:

1. Sends data
2. Wait for acknowledgment. If not received, backoff for random time and go back to step 1

There are several variations and potential improvements to the basic algorithm that change the backoff time, align transmissions to synchronized time slots and more. However, the basic characteristic of the algorithm remains. It does not check if the medium is busy before transmitting. As a result, the algorithm is prone to collisions. Mathematical analysis of the ALOHA algorithm shows that the maximum channel utilization is 18% and it is reached when the channel load is at 50%. It means that the dynamic range is very small. As long as the amount of traffic in the network (load) is very low, the network can scale. The moment the amount of traffic reaches above 20%-30% the collisions start to dominate and as a result more transmissions fail. Another problem of this network is that it is bounded. When the network is over loaded (above 100% load) it collapses. The delivered traffic falls down as the load increases. This characteristic impacts the ability of the network to deliver mission critical information in the event of sudden load increase as a result of an external event for example.

6 CSMA/CA Network Algorithm

CSMA/CA stands for Carrier Sense Multiple Access Collision Avoidance. A device that wants to transmit over the wireless medium must first listen and check if the medium is free or busy (carrier sensing). When the medium is free transmission can start based on internal backoff counter that is running inside the devices MAC layer. Each device randomize its backoff and counts it down. This way, when medium is cleared once one transmission ends, not all nodes start transmitting at once. Only the one (or ones) that have their backoff counter reached zero (collision avoidance). The backoff randomization window can be adaptive and increase with each failure. For example, devices randomize value between 0 to 15 at first and if packet transmission fails, they randomize between 0 to 31 for the retransmission. This adaptive mechanism allows the network to adapt to the actual load and network demand dynamically. The result is a robust network that minimizes the amount of collisions. As long as the channel load is below 100%, the channel utilization increases with the load. Once it reaches 100% and above, the utilization remains high. This algorithm performs well and its performance is much closer to the definition of a perfect network model described above. There are many common variants for CSMA algorithms. Some revolve around the decision to transmit once the medium is free. The backoff counter method discussed above is only one option. Other modifications are trying to solve the hidden node problem. The details of these variants are outside the scope of this document and readers can find many other resources on-line.

The illustration below compares the network performance as function of the load for ALOHA and CSMA/CA algorithms. It is clear that the dynamic range of ALOHA network is much smaller than the one of CSMA/CA network. In addition, the different behavior in the saturation region is illustrated demonstrating how the ALOHA network collapses.

Copyright © 2017, Texas Instruments Incorporated

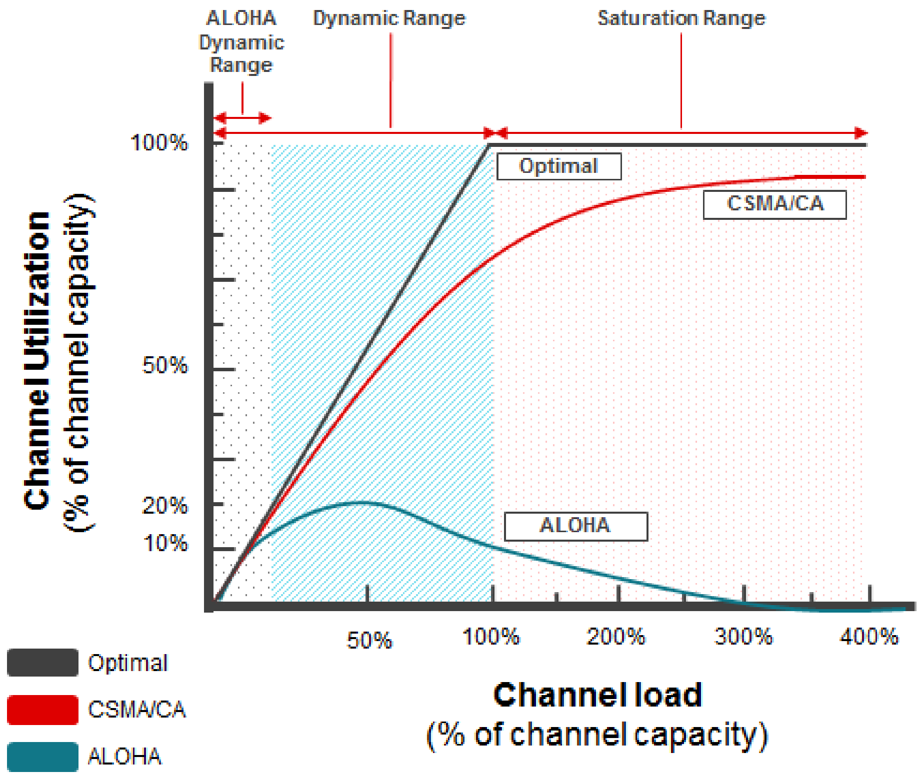

Figure 2. ALOHA vs CSMA/CA Performance

7 TI SimpleLink™ 15.4 Stack Offering Based on CSMA/CA

Texas Instruments has developed a networking solution that is based on IEEE 802.15.4e standard for its SimpleLink platform. The solution supports both Sub-1 GHz and 2.4 GHz and is part of the SDK provided by TI for TI SimpleLink devices CC1310 and CC1350. It is based on non-persistence CSMA/CA MAC layer and is very well suited all LPWAN use-cases. It supports beacon mode for synchronized networks, non beacon mode for unsynchronized networks as well as optional frequency hopping mechanism to improve network robustness and to increase the output power under FCC regulations.

The solution contains other built in networking features such as security, network management, addressing, commissioning, over the air software upgrade and more.

8 References

- *SimpleLink™ Sub-1 GHz CC13x0 Software Development Kit*
- *CC1310 SimpleLink™ Sub-1 GHz Ultra-Low Power Wireless Microcontroller*
- *CC1350 SimpleLink™ Ultra-Low Power Dual Band Wireless Microcontroller*

Copyright © 2017, Texas Instruments Incorporated

IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

Texas Instruments Incorporated ('TI") technical, application or other design advice, services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, "TI Resources") are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using any particular TI Resource in any way, you (individually or, if you are acting on behalf of a company, your company) agree to use it solely for this purpose and subject to the terms of this Notice.

TI's provision of TI Resources does not expand or otherwise alter TI's applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources.

You understand and agree that you remain responsible for using your independent analysis, evaluation and judgment in designing your applications and that you have full and exclusive responsibility to assure the safety of your applications and compliance of your applications (and of all TI products used in or for your applications) with all applicable regulations, laws and other applicable requirements. You represent that, with respect to your applications, you have all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. You agree that prior to using or distributing any applications that include TI products, you will thoroughly test such applications and the functionality of such TI products as used in such applications. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

You are authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED "AS IS" AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING TI RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY YOU AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

You agree to fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of your non-compliance with the terms and provisions of this Notice.

This Notice applies to TI Resources. Additional terms apply to the use and purchase of certain types of materials, TI products and services. These include; without limitation, TI's standard terms for semiconductor products http://www.ti.com/sc/docs/stdterms.htm), evaluation modules, and samples (http://www.ti.com/sc/docs/sampterms.htm).

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2017, Texas Instruments Incorporated