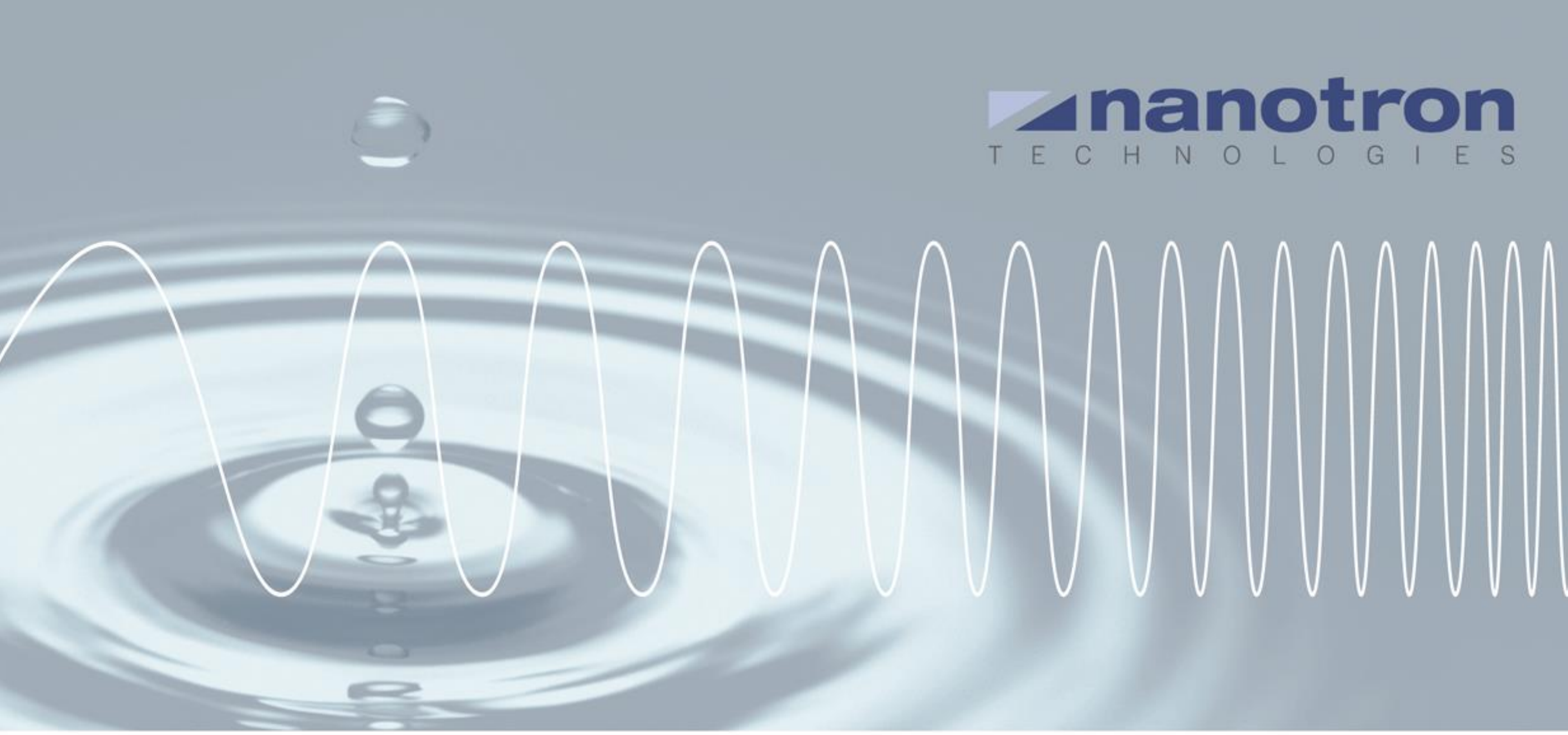

AN0512 Channel capacity in ranging applications

1.0

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Contents

1. Introduction

The behavior of a *swarm* bee alone in a certain area is very simple; it sends a short ID notification message (from now on referred as blink) to announce itself every period of time. When a neighbor appears the interaction between devices starts. At that moment the channel occupancy passes from one blink every period of time to two blinks and the two corresponding ranging operations that are automatically triggered. If a third swarm device appears in the area the number of blinks will become three and the number of automatic ranging operations will increase up to 6, as each blink will trigger the two *swarm* devices receiving it to initiate the ranging operation.
As we can see the number of messages in the air grows exponentially with the number of devices. Thus, it is important to set the *swarm* devices properly to avoid unnecessary transmissions, as well as to have an idea of the channel occupancy of our system. With this we can understand the limitations of our application. In this document we show what a ranging operation consist of and how long it takes. We will use this data to estimate the channel capacity. In we will finish with some recommendations to keep the channel occupancy under control and boost the performance of our application.

2. Ranging operation

2.1. Default ranging operation and its variants

Figure 2-1 shows a default ranging operation. 'default' means that the two *swarm* devices involved in the process have default settings. It consist of a ranging cycle (symmetrical double-sided two way ranging, SDS-TWR) plus the blink that triggers it and a last packet to broadcast the result.

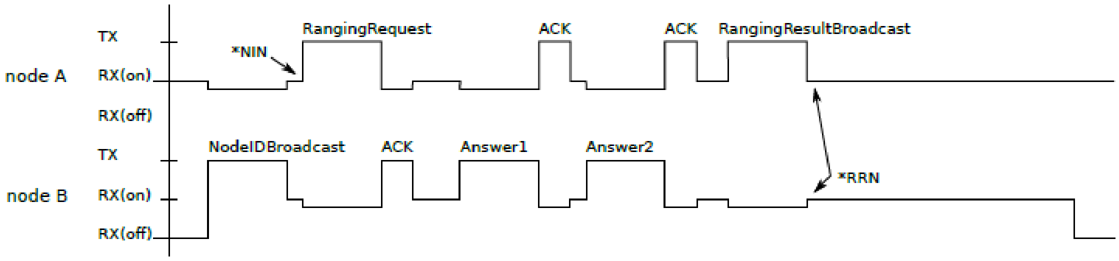

Figure 2-1: Default ranging cycle

Node B sends a NodeIDBoradcast (blink). Swarm bee A receives the blink and decides to start a ranging operation with node B. For that it send a RangingRequest to node B. Node B acknowledges the request (ACK) and accepts it by sending its answer 1. After receiving and ack to answer 1 from node A, node B sends its answer 2. When node A receives the answer 2, it acknowledges it (ACK), uses all the values it gathered to estimate the distance and sends the result both through the UART and over the air, as a broadcasted message ('RangingResultBroadcast'). All nodes receiving the RangingResultBroadcast will also pass it to their host though the UART.
At the RX (on) level of Figure 2-1 two slightly different levels can be seen. The upper one indicates that the node is in receive mode while the lower one indicates that the device is not only in receive mode but actually receiving information.
This default behavior can be modified. For certain applications the user could, for instance, disable the broadcasted message used to announce the estimated distances between pairs of nodes. It could also be possible that the user is more interested in triggering the ranging operation from the host and not automatically by the devices blink. In this case the blink would not be part of the ranging operation.

2.2. Basic ranging operation air time

The timing of the different packets exchanged during the ranging operation was measured and presented in our application note AN0501 [1]. We use the values shown in that document to estimate the air time per ranging cycle. The air time of a ranging cycle will be the addition of the times of RangingRequest, Answer1 and Answer2 and the three corresponding ACKs over the air. As it is shown in [1] the transmission time of each packet depends of the transmission mode selected. There are four variants: 80/1 (80 MHz bandwidth and 1 µs per symbol) and FEC off, 80/1 and FEC on, 80/4 (80 MHz bandwidth and 4 µs per symbol) and FEC off and 80/4 and FEC off. Table 2-1 reflects the air time of a ranging operation for the 4 transmission modes. The 3 scenarios considered are a ranging cycle, a ranging cycle triggered by a blink and a ranging cycle triggered by a blink and with the broadcast of the result (default ranging operation). The calculation was done with standard packets, without taking into account that some of the packets involved in the process can have a variable payload and, subsequently, variable length.

Table 2-1: Air time of a ranging operation for different modes

	80/1, FEC off	80/1, FEC on	80/4, FEC off	80/4, FEC on
SDS-TWR	1.45 ms	2.05 ms	4.92 ms	7.2 ms
Ranging + blink	1.95 ms	2.84 ms	6.82 ms	10.24 ms
Ranging + blink + result broadcast	2.58 ms	3.86 ms	9.26 ms	14.26 ms

2.3. Length of the packets involved in ranging

The timing showed in the previous section depends also on the length of each packet transmitted. The packets consist of a fix part, or header, and a variable part, or payload. The payload of each of them is different depending on its function:

NodeIDBroadcast (blink):

SWARM_TYPE – 1 byte
SWARM_VERSION – 1 byte
SWARM_DC – 1 byte
SWARM_SPSA – 1 byte
SWARM_WAKEUP_REASON – 1 byte
SWARM_LENGTH – 1 byte
SWARM_SENSOR_DATA_LENGTH – 1 byte
SWARM_SENSOR_DATA - BATTERY – 3 bytes
GPIO – 2 bytes
TEMPERATURE – 3 bytes
ACCELERATION – 7 bytes
TIMESTAMP – 5 bytes
ESC – 1 byte

This makes a total of 28 bytes.
When the MEMS data is disabled, the temperature and acceleration data is not added to the packet and the payload is only 18 bytes.
Additionally, user data can be added to the NodeIDBraodcast using the API command FNIN (see [2]). The length of the user data can be such that the maximum payload length is 128.

RangingRequest:
By default it only includes 12 bytes of ranging data. The user can include application data (user data) by using the API command FRAD (see [2]). The extra data can have up to 116 bytes of length, so that the maximum payload is also 128 bytes.

Answer1:
It only includes 12 bytes of ranging data. This is fixed and cannot be changed.

Answer2:
It only includes 12 bytes of ranging data. This is fixed and cannot be changed.

RangingResultBroadcast:
It is similar to the NodeIDBroadcast packet but instead of user data it includes the ranging result.
Ranging result:
SOURCE_ID – 6 bytes
DESTINATION_ID – 6 bytes
ERROR_CODE – 1 byte
DISTANCE – 4 bytes
This means (28 + 18) = 46 bytes when the sensors are enabled and (18 + 18) = 36 bytes when the sensors are disabled.

3. Channel capacity

Using the data in Table 2-1, we can do a simplified estimation to get an idea of the channel capacity. A first estimation is done for the ranging cycle using transmission mode 80/1 and FEC off and with the default packet length. A blinking rate of one second is assumed. The reasoning followed is:

- The ranging cycle consists of several consecutive packets. The total accumulative air time used for one SDS-TWR ranging cycle is the addition of the air time of all the packets, about 1.45 ms. We will consider one ranging cycle as one 1.45 ms event.
- There is a total of 1000 ms / 1.45 ms ~ 689 ranging slots per second = theoretical capacity.
- Since ranging events (= access to the medium air interface) are totally random, one could use ALOHA statistics:
  Between 17 and 19% of the theoretical capacity could be used providing the over-all load is not more than 50% of the total. This means between 117 and 131 ranging events per second are going to be successful providing the total number of attempts does not exceed 344 per second.
- Conclusion: Expect a capacity of about 117 ranging events per second while limiting the total number of attempts to 344 or less.

The same methodology is followed when the ranging operation is triggered by a blink and the ranging result is broadcasted. We will take into account the air time for the RangingResultBroadcast and the NodeIDBroadcast.
According to this values, the expected capacity, in ranging events per second, providing the over-all load is no more than 50% is shown in the following table:

Table 3-1: Number of ranging cycles per second for different modes

	80/1, FEC off	80/1, FEC on	80/4, FEC off	80/4, FEC on
SDS-TWR	117	83	35	24
Ranging + blink	87	60	25	17
Ranging + blink + result broadcast	66	44	18	12

4. Coexistence of multiple swarms in the same area

As already explained, when multiple tags with the default configuration share the same area the number of packets in the air grows fast. And with the increase of the number of packets on the air, the probability of packet collisions will also increase. Even when our application is far below the maximum capacity of the channel, the probability of packets colliding exist. But, what happens when a packet is lost over the air?
Except for the NodeIDBoradcast and the RangingResultBroadcast, all the packets that intervene in a ranging operation should be acknowledge by the receiver. If they are not, they are retransmitted up to three times. If, after a third retransmission, no answer is received from the receiver node, the transmitting device will stop. When a device sends a RangingRequest and it receives an ACK, it starts a timer. If the timer expires and the ranging operation has not been completed, the node aborts it and pass a RRN to the host indicating 'time-out' error. This timer initializes at a fixed value of 7ms for the transmission mode 80/1 and 13ms for the mode 80/4, and cannot be changed by the user.
The following figures show different scenarios in which one of the packets involved in the ranging is lost or not transmitted. Figure 4-1 shows the scenario in which the rangingResultBraodcast option has been disabled. After receiving the answer2, node A sends the acknowledgement (ACK), estimates the distance and passes it to the host as a RRN.

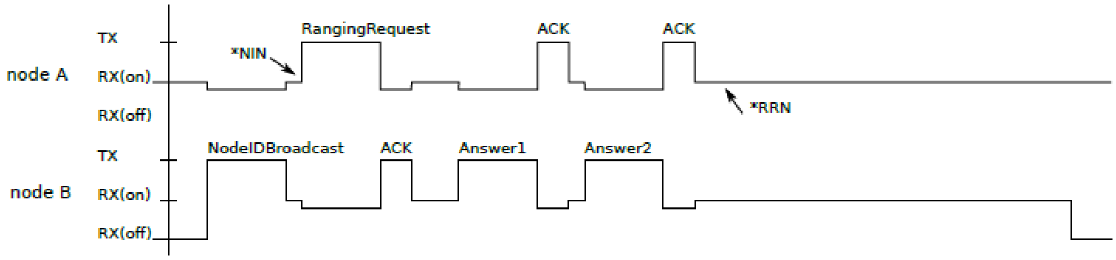

Figure 4-1: Ranging cycle without result broadcast

Figure 4-2 shows the scenario in which one of the ACK gets lost. Node B does not receive any ACK for its answer1, so it sends it for a second time. When the ACK is finally received, node B continues the normal process.

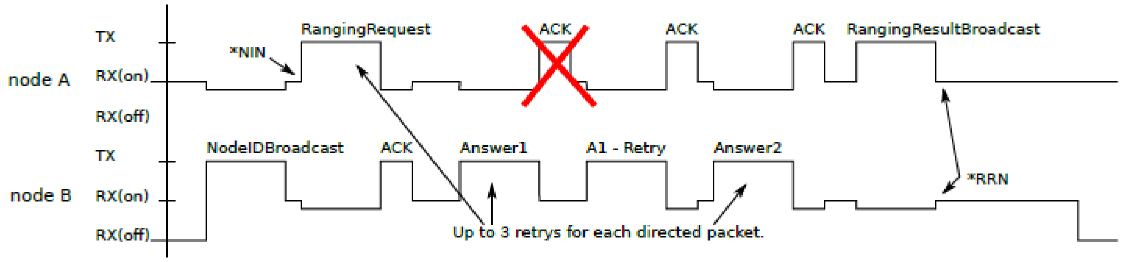

Figure 4-2: Ranging cycle with an ACK lost

In the scenario depicted in Figure 4-3 node B is in privacy mode. After sending its blink it receives a RangingRequest from node A and acknowledges it. However, it does not want to perform the ranging so it does not send Answer 1. After a while, the timer at node A will time-out and node A will pass a RRN to the host indicating the error.

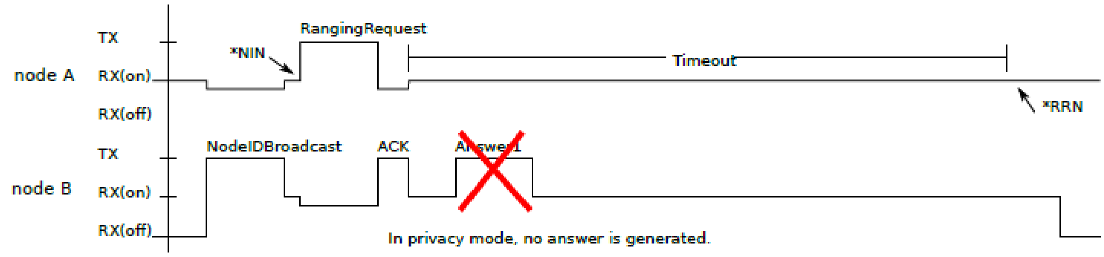

Figure 4-3: Scenario where one of the nodes is in privacy mode

5. Recommendations

Taking into account the different aspects shown in this document, there are some recommendations that can by followed in order to boost the application's performance:

- Sending more blinks than necessary triggers unnecessary ranging operations and may cause the channel saturation causing that the actual number of estimated ranges is less than the required. For this reason it is recommended to adjust the blinking rate to the application requirements.
- It is not always necessary that a device react to the blinks of other devices. Using device classes the *swarm* bee's can be set so that only ranges to devices from a determined class. For instance the devices can be configured in such a way that, in a collision avoidance application with workers and vehicles, they range between workers and vehicles but not among workers. The data transmission inside the blink and the broadcast messages is very interesting feature for some applications. However, if the information is no longer needed, it is recommended to clear the register, so that no useless data is sent.
- Until now we have assumed that the devices transmit whenever they have to. When the area is highly populated, sometimes the message will get through and arrive to the destination, other times it will collide with other packets originated by other devices. This means that the devices need to retransmit again, and, thus, waste channel capacity. To have a more efficient use of the channel the listen before talk technique is recommended. This is set using the CSMA command of the API. When the devices perform CSMA, a swarm bee that wants to transmit will first listen to the channel and, if there is another device transmitting, it will wait. After a while it will listen again, then it will detect that the air interface is silent and it will transmit its message. In this way collisions and retransmissions will be avoided.
  There are two CMSA modes available in swarm devices: symbol detection and energy detection. The symbol detection prevents the swarm device from transmitting when other swarm devices are doing it. When other radio systems working in the same frequency band are present in the area, for instance WiFi, it is more convenient to select CSMA in energy detection mode. This mechanism prevents the nodes from transmitting when the energy detected in the channel is higher than a certain threshold. Thus, it avoid collisions not only with swarm devices but also with any other transmitting device.

6. References

[1] AN0501 – *swarm* bee Ranging Operation Time – v1.1, Nanotron Technologies
[2] *swarm* API Description – v2.1, Nanotron Technologies

Document History

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9/8/2015	MLA	1.0	Initial version

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