APS001 APPLICATION NOTE

DW1000 POWER CONSUMPTION

System related aspects of Power Consumption and how to optimize them when using the DW1000

Version 2.1

This document is subject to change without notice

TABLE OF CONTENTS

TABLE OF FIGURES

LIST OF TABLES

1 INTRODUCTION

This is one in a series of notes on the use and application of Decawave's Ultra Wideband technology.

This note examines some of the system-related concepts and tradeoffs that need to be considered to achieve best possible power consumption.

It assumes the reader is familiar with the concepts and principles behind Wireless Communications in general and the DW1000 in particular – for more information see the Decawave website www.decawave.com.

Other notes in this series, also available on www.decawave.com, include technical details of the DW1000 and examine the application of Decawave technology to market areas such as Electronic Shelf Labeling, Process Automation, Healthcare, Logistics and so on.

2 POWER CONSUMPTION OF WIRELESS TRANSCEIVERS IN GENERAL

2.1 Introduction

The accurate determination of the power consumption of a wireless transceiver from a systems point of view is actually a very tricky thing to do. It depends primarily on two things: -

- The actual power consumed by the wireless subsystem in its various modes of operation
- The amount of time spent in each of those modes

To minimize power consumption requires that the wireless subsystem spend as little time as possible operating and when it is operating it spends as little time as possible in higher-power states and as much time as possible in lower-power states.

The first is mainly determined by the designers of the wireless technology used (chips, modules or subsystems) and the system designer generally has little control here apart from, perhaps, reducing the transmitted RF power when long range operation is not necessary thereby reducing power consumption.

The second, however, is heavily influenced by protocol choices made by the system designer.

2.2 The implications of protocol choice

The protocol and system configuration choices the system designer makes can have major implications for the power consumption of individual elements of the system.

Consider two different scenarios illustrated in Figures 1 & 2 below. Both involve a master polling a slave for a response

For both Master and Slave the average power consumption over one second can be calculated by considering the time spent in the various modes of operation: -

Table 1: Power consumption elements

Time	Associated Power Consumption
T_s: Time spent sleeping	P_S: Sleep power
T_{TX}: Time in Transmit Mode	P_{TX}: Transmit power
T_L: Time listening for response	P_L: Power in Listen mode
T_{RX}: Time receiving response	P_{RX}: Receive power

2.2.1 “No Synchronization” case

In the first of these scenarios there is no synchronization between the master and slave. The master polls the slave at random intervals requiring the slave to continually listen for polls and respond when a suitably addressed poll is received.

The power consumption of the Master is entirely under its own control. It sleeps, wakes, polls the slave, waits for a response and goes back to sleep

Slave power consumption is dictated by the duty cycle of the master. The longer between polls the longer the slave spends listening.

CASE 1: ASYNCHRONOUS POLLING CONFIGURATION

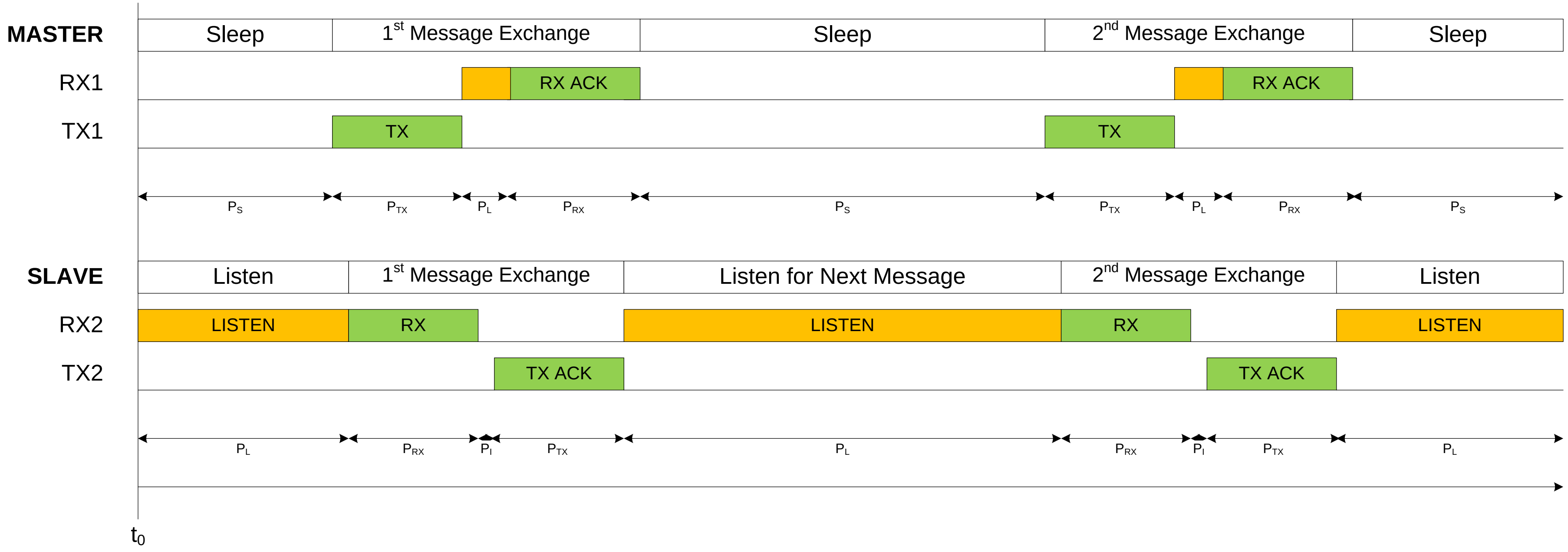


Figure 1: Asynchronous Polling – Single Slave

Because the slave does not know when messages will arrive it needs to listen constantly. When it does receive a message it responds and then returns to listening mode.

The relationship between I_{dd} in listening mode vs. I_{dd} in Rx & Tx modes is very important in determining overall consumption.

The situation becomes even more complex from a power consumption point of view when there are multiple slaves because all slaves receive all messages. Each slave analyses the received messages to determine which are addressed to it and then either accepts or discards them. Having each slave receive polls that are not addressed to it is a complete waste of power as we can see in Figure 2.

Figure 2: Asynchronous Polling – Multiple Slave

We can make one compromise here in that once a slave realizes a poll is not addressed to it, it can sleep for the period of the acknowledgment from the slave to which the poll is addressed. If we don't do this then all slaves will receive acknowledgments from all the other slave nodes making the power consumption situation even worse.

2.2.2 "Synchronized" Case

Now consider the case of a synchronous polling configuration: -

CASE 3: SYNCHRONOUS POLLING CONFIGURATION

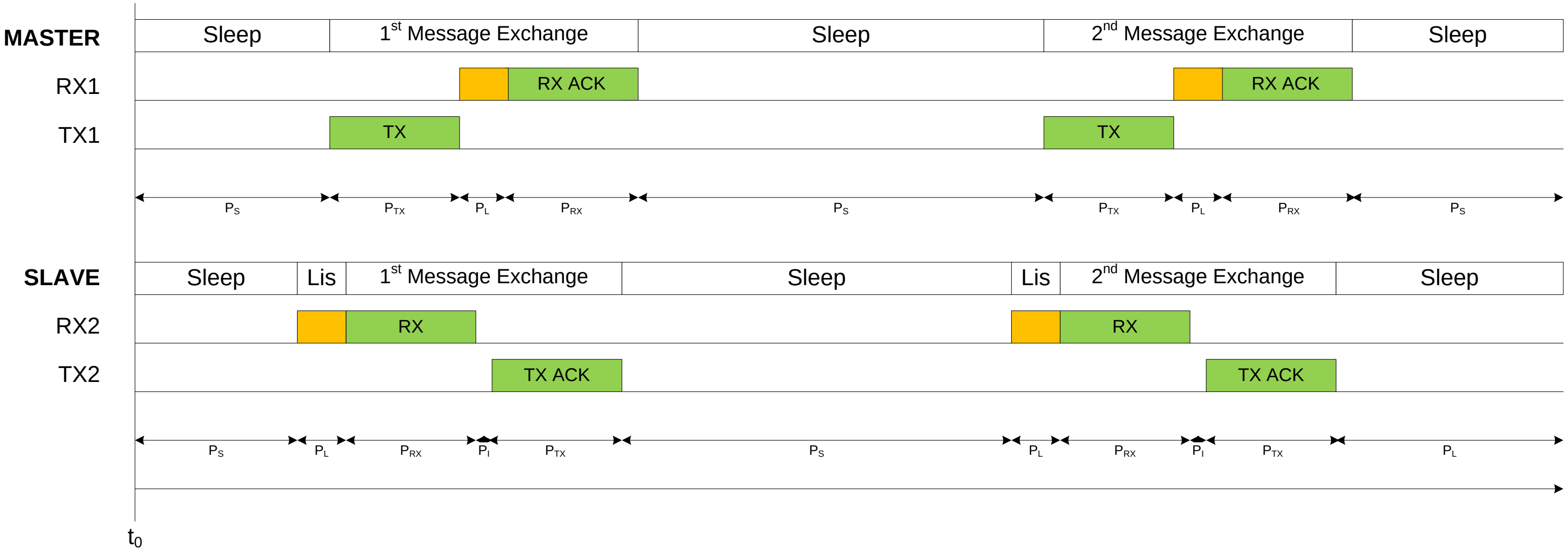


Figure 3: Synchronous Polling – Single Slave

In this scheme, the Master and Slave are synchronized in one of a number of different ways so that the Slave knows when to expect a poll from the Master. In this case the Slave can wake up shortly before a poll is due, receive the poll, respond and return to sleep. Clearly this has a very large & beneficial impact on power consumption. The effect, from a system point of view, is even more dramatic when we extend this concept to multiple nodes.

CASE 4: SYNCHRONOUS POLLING CONFIGURATION – MULTIPLE SLAVES

Figure 4: Synchronous Polling – Multiple Slaves

Here, once synchronized, each slave only receives the poll addressed to it thereby significantly reducing power consumption over the unsynchronized case.

It is not the purpose of this note to discuss the implementation details of such schemes, particularly the synchronization scheme; there is a wealth of literature available on these topics. The intention here is simply to illustrate the very significant effect that the choice of system architecture can have on individual node power consumption.

3 POWER CONSUMPTION IN TWO WAY RANGING APPLICATIONS

3.1 Introduction to Two-Way Ranging Schemes

Two Way Ranging systems are a class of RTLS in which a tag and a fixed node exchange information and by doing so can calculate the distance between themselves knowing the speed of light.

These are more fully described in [5].

An overview of Decawave's implementation of this scheme is given in Figure 5

There are some obvious observations here: -

1. Ranging to 3 anchors sequentially in time is a relatively slow process and significant motion of the tag between ranges can result in a location error
2. To derive one location requires a minimum of 3 ranging measurements. A single ranging measurement requires 3 messages; therefore 9 messages are required in total; so two way ranging occupies 9 times more air time than a simple tag-blink and therefore the tag density achievable in TWR is approximately 9 times less than that achievable with TDOA although other factors do play a part also.
3. The tag must be both a transmitter and receiver; as a result its power consumption is higher than one which is just a transmitter

Tag sees Round Trip, T_{RT}, of (T_{RR} - T_{SB})
Reader sees Round Trip, R_{RT}, of (T_{RF} - T_{SR})

Reader knows all times, so it can:
(a) remove its response time: (T_{SR} - T_{RB}) from the Tag's T_{RT},
(b) remove tags response time: (T_{SF} - T_{RR}) from Reader R_{RT},
to give antenna to antenna round trip times

Reader then can combine these two resultant round trip times (by averaging) to remove by effects of each ends clock differences, and then divide by 2 to get one way trip time.

Multiplying by 'c' the speed of light (and radio waves) gives the distance (or range) between the two devices:
$((T_{RR} - T_{SB}) - (T_{SR} - T_{RB}) + (T_{RF} - T_{SR}) – (T_{SF} - T_{RR})) / 4c$

or $(2T_{RR} - T_{SB} - 2T_{SR} + T_{RB} + T_{RF} - T_{SF}) / 4c$.

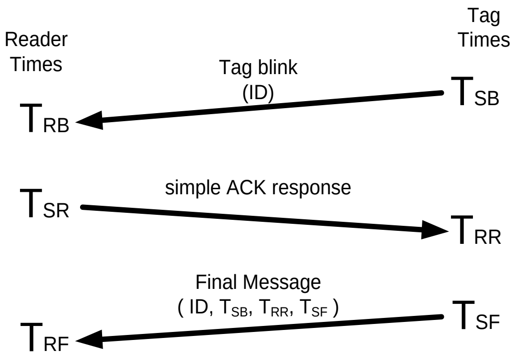


Figure 5: Two-Way Ranging exchange

This section examines some of the system issues that contribute to tag power consumption in a two-way ranging system. For the purposes of this discussion it is assumed that the anchor nodes are mains powered and their power consumption is not so much of an issue compared to tag power consumption.

3.2 Time & Power

3.2.1 Introduction

Power consumption of a tag in a two-way ranging scheme depends on the time it spends in each of its operating states and the power consumption of each of those states. So in order to address the issue of power consumption it is necessary to first consider the timings involved.

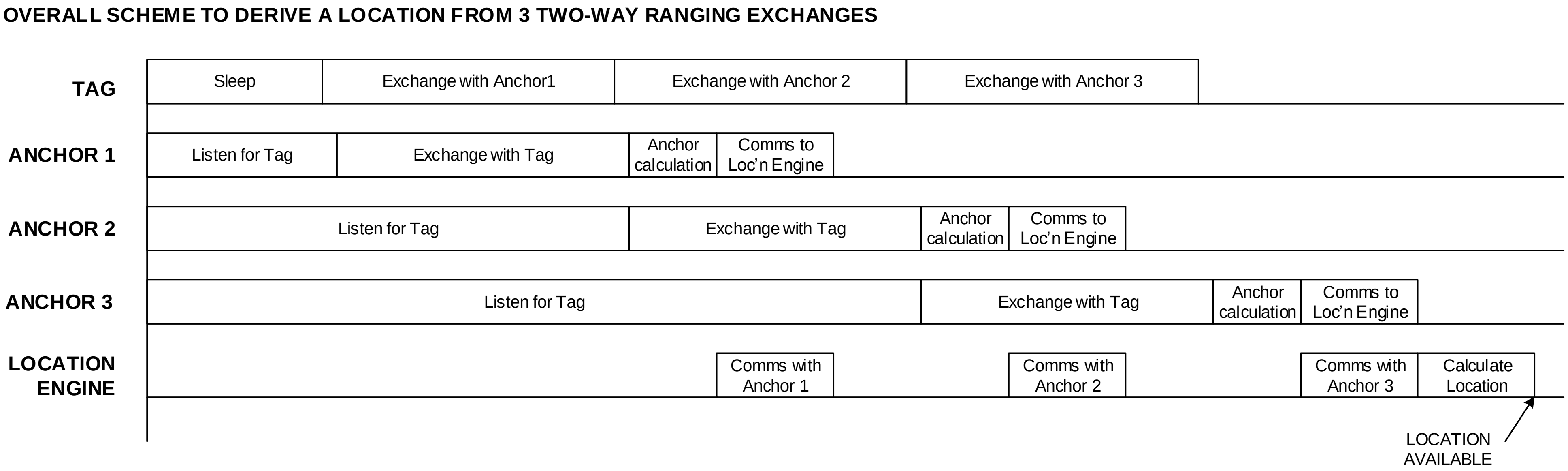


Figure 6: Overall location scheme using two-way ranging

3.2.2 Overall time to derive a location

The calculation of one location involves the following steps: -

1. The tag ranges to the first anchor – the first anchor provides the resulting distance measurement to the location engine
2. The tag ranges to the second anchor - the second anchor provides the resulting distance measurement to the location engine
3. The tag ranges to the third anchor - the third anchor provides the resulting distance measurement to the location engine
4. The Location Engine calculates the location of the tag

The total time to establish a location for one tag therefore depends on: -

1. The time take to perform each range
2. The time between ranges
3. The time taken to calculate the range at the last anchor
4. The time taken to communicate that last range to the location engine (on the assumption that measurements from the other previous anchors have already reached the location engine)
5. The time taken for the location engine to solve between the resulting spheres.

This overall sequence is shown in Figure 6.

The breakdown of a single ranging exchange is discussed in 3.2.2.1 and presented in Figure 7

3.2.2.1 Time taken to perform each range

The time taken to perform a single range measurement depends on a number of parameters as shown in Figure 7.

TAG POLLS ANCHOR AND DOES TWO-WAY RANGING SEQUENCE

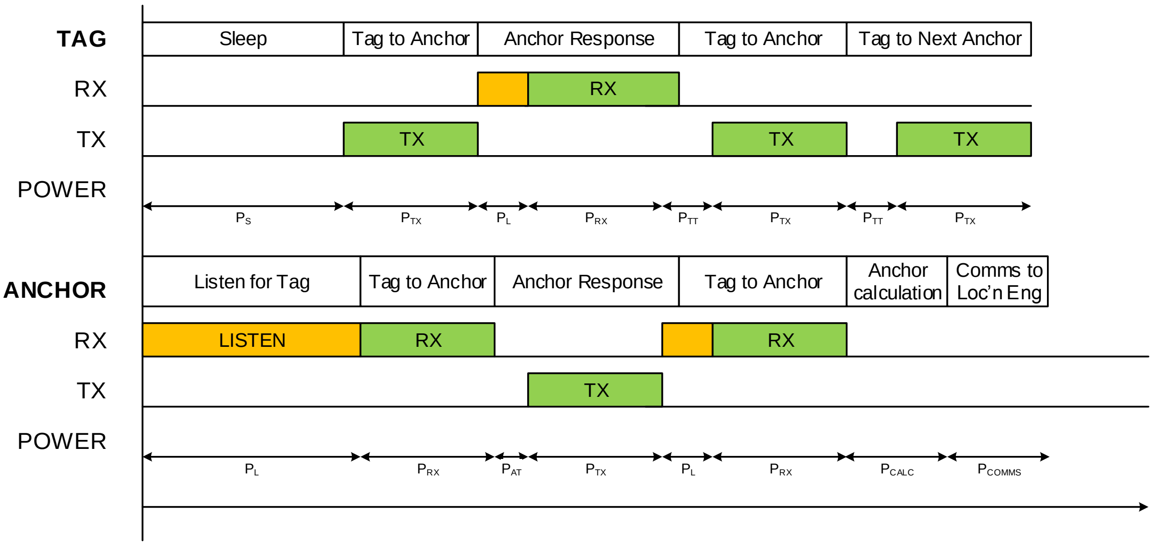


Figure 7: Single two-way ranging transaction with communications to location engine

The various elements of the exchange and the parameters on which they depend are analysed as follows: -

Table 2: Components of time taken to perform a single two-way ranging exchange

Parameter	Description	Dependency
Message Transmission time	Time taken for Tag / Anchor to transmit / receive message	Depends on data rate & preamble length – shorter preambles, minimum length payloads & high data rate will keep this short
Anchor turnaround time	Time taken for Anchor to begin transmitting response when valid message received from Tag	Rate at which data is read out from / written into DW1000 (SPI clock frequency) Processing speed of anchor – processor / clock frequency dependent
Tag turnaround time	Time taken for Tag to begin transmitting response when valid message received from Anchor	Rate at which data is read out from / written into DW1000 (SPI clock frequency) Processing speed of tag – processor / clock frequency dependent
Anchor calculation time	Time taken by anchor to perform necessary calculations based on timestamps and produce time-of-flight / distance result	Processing speed of anchor – processor / clock frequency dependent

3.2.2.2 Time between ranges

The time between the tag ranging to the first anchor and subsequently ranging to a second anchor is determined by how quickly the tag can turn-around from sending the last message of the ranging exchange with the previous anchor to sending the first message of the ranging exchange with the next anchor.

This assumes that the tag is aware of which anchor to interact with next and does not have to search for it.

Note also that in reality before commencing a ranging exchange the tag will need to listen briefly to see if any other ranging exchange is taking place on the same channel and if it is, it will need to “back off” a random amount of time before attempting to range again.

3.2.2.3 Time taken to calculate distance

Once all timestamps have been gathered at the anchor it must perform some calculations to derive the time of flight / distance. These are generally relatively simple arithmetic operations but nonetheless do take some finite time. The speed of this calculation depends entirely on the architecture and processing capability of the processor employed in the anchor.

DW1000 timestamps are 40-bit numbers so working with them is more difficult on 16-bit machines than 32-bit machines and will take longer.

3.2.2.4 Time taken to communicate with the Location Engine

This depends almost entirely on the communications scheme & protocol employed between the anchor and location engine. It is difficult to advise here expect to say that the minimum communications speed required must be greater than the expected aggregate tag ranging rate across all tags otherwise the anchor will be swamped with calculated ranges that it cannot forward to the location engine.

3.2.2.5 Time taken for Location Engine to derive a solution

This depends on the algorithm used in the location engine and the speed at which that algorithm is processed by the host machine: -

- Clearly a faster machine will process a given algorithm more quickly and thereby produce a result in a shorter time.
- The choice of algorithm, for a given machine, will determine how quickly a location can be derived

3.3 Impact of the above on Power Consumption

3.3.1 Reducing ranging power consumption

As mentioned in 3.2.2 above the primary method of reducing overall power consumption while keeping system capacity to a maximum is to minimize the amount of time taken during transmission and reception of data and maximise the amount of time spent in low current states or in the OFF state. To do this requires: -

1. Using the highest data rate possible
2. Keeping the number of data bytes as low as possible
3. Keeping the turnaround time between Transmit and Receive modes as short as possible by ensuring the anchor / tag code is efficiently written.
4. Keeping the time between the completion of the ranging exchange by the tag with one anchor and the start of the exchange with the next as short as possible by ensuring the tag code is efficiently written
5. Returning to SLEEP / DEEP SLEEP / OFF as quickly as possible after the last ranging exchange is complete

4 POWER CONSUMPTION IN TDOA RTLS APPLICATIONS

4.1 *Introduction to TDOA systems*

Time Difference of Arrival systems are a class of RTLS in which the difference in the times of arrival of a signal at known physical points is used to derive information about the physical location of the device transmitting that signal.

These are more fully described in [5].

4.2 *Time & Power*

4.2.1 Introduction

Power consumption of a tag in a TDOA scheme depends on the time it spends in each of its operating states and the power consumption of each of those states. So in order to address the issue of power consumption it is necessary to first consider the timings involved.

4.2.2 Overall time to derive a location

In a TDOA based RTLS, the tag simply broadcasts a message (referred to as a “blink” in the text below), which includes its unique identifier, to however many anchors are in range. The difference in arrival times at each of the anchors provides information on the location of the tag. Each pair of arrival times defines a hyperbolic curve on which the tag lies. Solving for the intersection of those curves yields the position of the tag.

The calculation of one location involves the following steps: -

1. The tag broadcasts its blink
2. Each anchor receives the blink and provides the resulting arrival time to the location engine
3. The Location Engine calculates the location of the tag

The total time to establish a location for one tag therefore depends on: -

1. The time taken for all anchors to receive & time-stamp the tag’s blink
2. The time taken to communicate all time-stamps to the location engine
3. The time taken for the location engine to solve between the resulting spheres.

This overall sequence is shown in Figure 6. This assumes that each anchor can communicate with the location engine while simultaneously listening for tag blinks.

The breakdown of a single ranging exchange is discussed in 3.2.2.1 and presented in Figure 7.

OVERALL SCHEME TO DERIVE A LOCATION USING TDOA

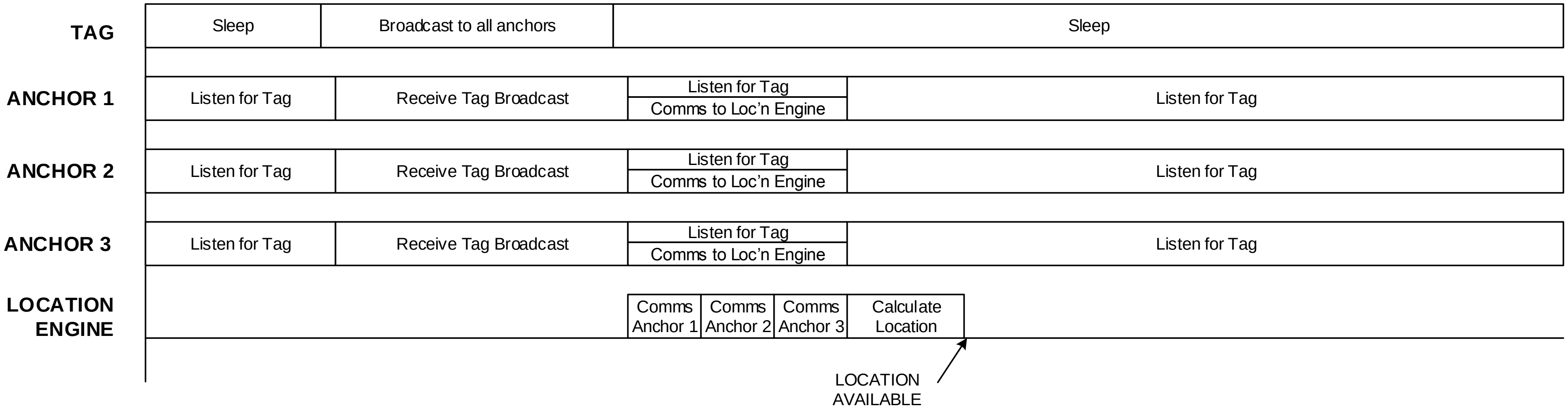


Figure 8: Overall location scheme using TDOA

4.2.2.1 Time taken to receive and timestamp a tag blink

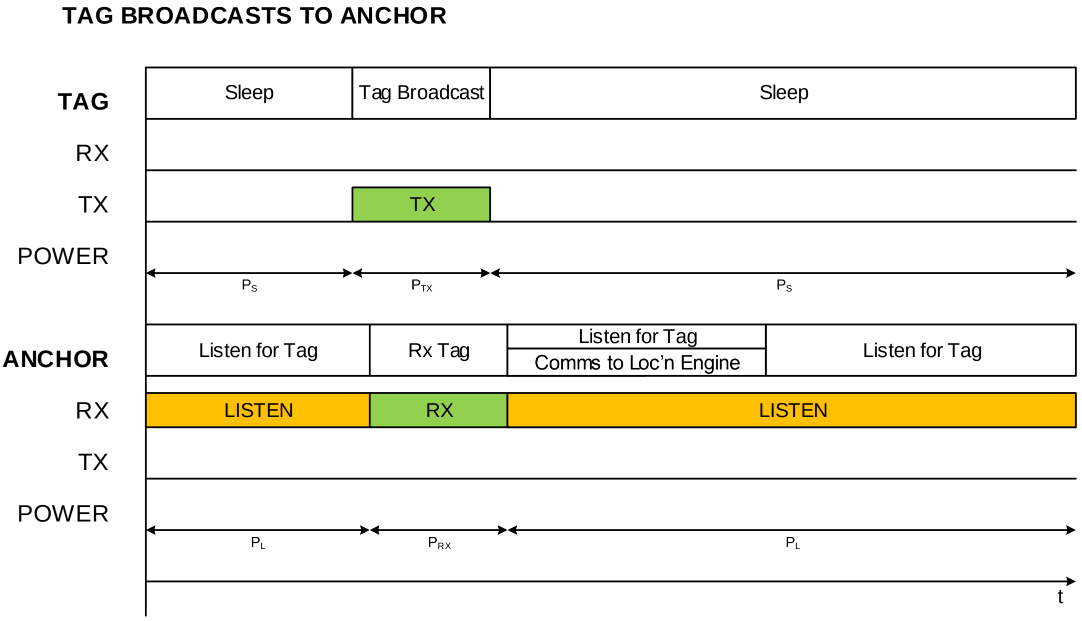


Figure 9: Tag transaction with individual Anchor node

Because the tag blink is a broadcast the time taken to receive and timestamp it depends on the particular parameters of the message; its preamble length, its payload content and the data rate at which that payload is transmitted. Refer to section 5.2 for further discussion of this topic.

4.2.2.2 Time taken to communicate with the Location Engine

This depends almost entirely on the communications medium & protocol employed between the anchor and location engine. It is difficult to advise here except to say that the minimum communications speed required must be greater than the expected aggregate tag blink rate across all tags in range of a given anchor otherwise the anchor will be swamped with receive timestamps that it cannot forward to the location engine.

4.2.2.3 Time taken for Location Engine to derive a solution

This depends on the algorithm used in the location engine and the speed at which that algorithm is processed by the host machine: -

- Clearly a faster machine will process a given algorithm more quickly and thereby produce a result in a shorter time.
- The choice of algorithm, for a given machine, will determine how quickly a location can be derived

5 COMMON POWER CONSUMPTION CONTROL METHODOLOGIES

5.1 Introduction

A good understanding of the performance requirements of your RTLS can allow the use of various system-level methodologies to minimize power consumption.

Ultimately, from a tag perspective, these relate to controlling what the tag is communicating and how often that communication takes place.

5.2 Tag message length optimization / dynamic modification

5.2.1 Introduction

As explained in [2] an IEEE802.15.4-2011 UWB message consists of a number of distinct parts. It is important to optimize each of these components to achieve maximum power efficiency.

5.2.2 Message Preamble Optimization

The preamble sequence length in an 802.15.4 UWB message is configurable. The choice of preamble length depends on a number of system goals and constraints of which power consumption is only one but in general the preamble should be set to the shortest one possible that still achieves satisfactory range performance. In this way on-air time is optimized and power consumption in the transmitter minimized.

5.2.3 Message Payload optimization

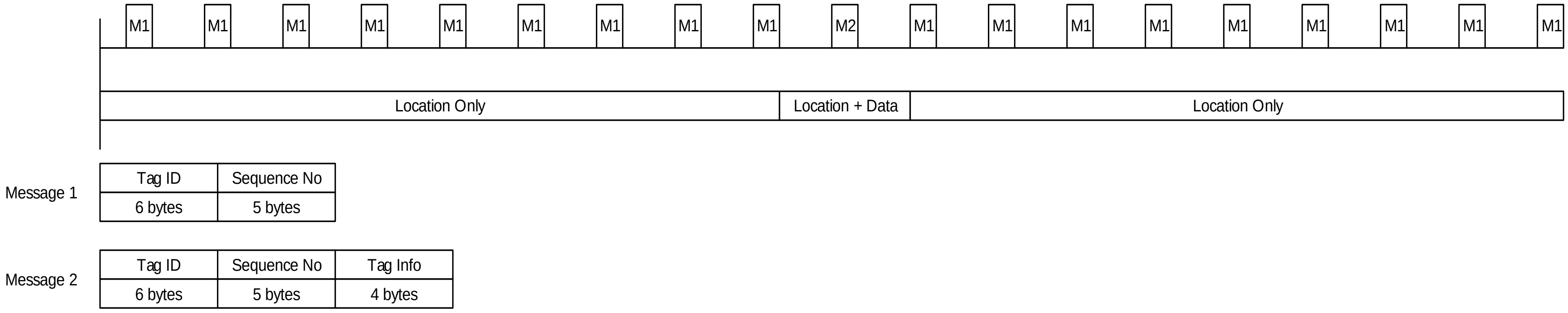
A tag message needs to contain certain information for it to be used in an RTLS scheme and those contents depend on the choice of scheme. (TWR / TDOA etc.). Beyond that, the tag can report additional information such as battery voltage, tag ambient temperature, push-button status, and other ambient information.

Keeping the tag message to the minimum necessary for the tag’s location to be derived achieves the best possible power consumption. Transfer of additional information increases power consumption. Careful consideration should therefore be given to how often this additional information is reported.

In many cases it is not necessary to report tag battery voltage very often because it changes slowly compared to the location of the tag which can change rapidly. Similarly, ambient conditions generally change slowly (although this is very application dependent) and need not be reported as often as the location of the tag.

Consideration should therefore be given to defining a number of tag message types the shortest of which is the one used most often (for location only) and the largest of which is used least often (reporting location plus multiple environmental variables). In this way, power consumption of the tag transmission can be optimized. See Figure 10m for examples of this.

Consideration should also be given to defining thresholds in the tag for parameters such as temperature / battery voltage and only reporting their values by exception if they cross these alarm thresholds. This is common practice in industrial control systems and those techniques are valid here.



Message 1

Tag ID	Sequence No
6 bytes	5 bytes

Message 2

Tag ID	Sequence No	Tag Info
6 bytes	5 bytes	4 bytes

Figure 10: Dynamic message payload modification

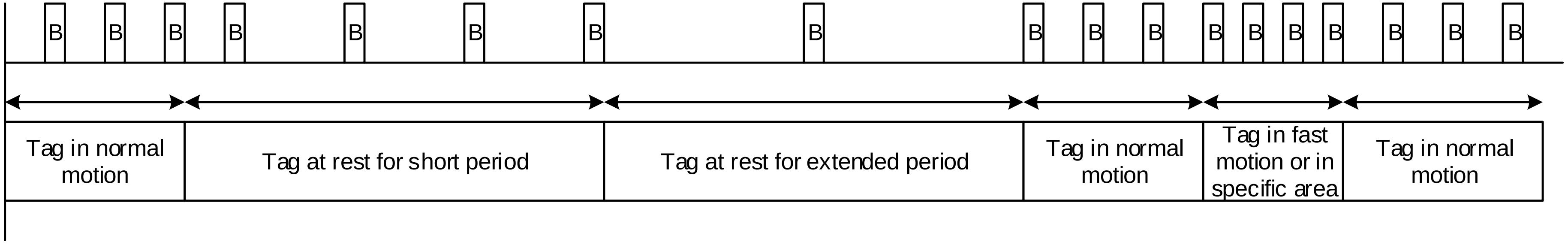


Figure 11: Tag dynamic update rate modification

5.3 Tag update-rate optimization

The next parameter to consider is how often the tag location is updated. There is considerable scope here for power reduction in both TWR and TDOA systems.

A tag at rest and not in motion does not need to update its position as often as when it is in motion and the rate of update when in motion is dependent on many variables including the speed of motion and the area in which the tag is moving (safe area / unsafe area etc.).

Consideration should be given to the use of accelerometers or other motion sensing technologies in the tag so it can dynamically adjust its ranging rate. See Figure 11 for examples of this.

5.4 Optimizing the receive window in the tag

The receiver in the DW1000 uses more power than the transmitter. Consequently it is beneficial from a power consumption point of view to minimize the time spent in receive mode.

5.4.1 Two-way ranging

In a Two Way Ranging scheme, when a tag has transmitted a message to a known anchor and is expecting a response within a specified time (based on the turnaround time of the anchor) it can, depending on that known turnaround time, enter IDLE / SLEEP mode while waiting for the response and only enable its receiver at the required time.

Consideration should be given to the use of one of the low power SNIFF modes described in the DW1000 User Manual (Ref [3]) depending on the time restrictions in your system.

5.4.2 TDOA

In a TDOA scheme a tag generally is not required to act as a receiver to allow its location to be determined. Nonetheless it may be desirable for the system to communicate with the tag for a number of reasons: -

- To adjust some of the tag operating parameters – update rate, for example
- To shut the tag down – if it is entering an area where UWB is not permitted

To allow this to happen the tag can, as part of its normal location message, send a request interrogating the infrastructure to determine if there are any commands pending for it. The tag can then wait a pre-determined time and open its receiver for short time to receive any incoming message from the infrastructure. Should a message arrive the tag can receive and act on it and if necessary confirm reception either in its next scheduled broadcast or immediately depending on the message content.

If message preamble is not detected during the receive window then the tag will time out and return to sleep pending the next location broadcast.

6 REFERENCES

Reference is made to the following documents in the course of this Application Note: -

Table 3: References

Ref	Author	Version	Title
[1]	Decawave	Current	DW1000 Data Sheet
[2]	Decawave	Current	DW1000 User Manual
[3]	Decawave	Current	UWB Worldwide Regulations
[4]	Decawave	Current	DW1000 Software Application Programming Interface (API) Guide
[5]	Decawave	Current	APS003 Introduction to RTLS

7 REVISION HISTORY

Table 4: Revision History

Revision	Date	Description
1.0	19th August 2013	Internal Release
1.1	9th September 2013	Interim release with additional material
2.0	10th December 2013	Formal release
2.1	31st December 2015	Scheduled update

8 MAJOR CHANGES

Revision 2.0

Page	Change Description
All	Formal release

Revision 2.1

Page	Change Description
All	Update of version number to 2.1 / Copyright notice to 2015
All	Various typographical / formatting corrections
23	Update to Idd figures in table 5 to match those in [1]

9 ABOUT DECAWAVE

Decawave is a pioneering Fabless semiconductor company whose flagship product, the DW1000, is a complete, single chip CMOS Ultra-Wideband IC based on the IEEE 802.15.4-2011 UWB standard. This device is the first in a family of parts that will operate at data rates of 110kbps, 850kbps and 6.8Mbps.

The resulting silicon has a wide range of standards-based applications for both Real Time Location Systems (RTLS) and Ultra Low Power Wireless Transceivers in areas as diverse as manufacturing, healthcare, lighting, security, transport, inventory & supply chain management.

Further Information

For further information on this or any other Decawave product contact a sales representative as follows: -

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e: sales@decawave.com
w: www.decawave.com

APPENDIX 1: DW1000 OPERATING STATES

In order to minimize consumption the DW1000 should be kept in the lowest power consumption state as much as possible and in the highest consumption state for the least time required to fulfill the necessary function. In order of decreasing power consumption at a given data rate these states are: -

Table 5: Power Consumption of various device states in decreasing order

Operation	Ranking	Power Consumption
Receiving Preamble	Highest	Depends on configuration
Receiving Data	|	Depends on data rate
Transmitting Preamble	|	Depends on configuration
Transmitting Data	|	Depends on data rate
IDLE State	|	19 mA (PLL locked)
INIT State	|	5 mA (XTAL Osc running)
SLEEP State	|	1 µA
DEEP SLEEP State	V	50 nA
Off	Lowest	None

These power modes are discussed in much greater detail in the DW1000 User Manual [2] and power consumption figures are provided in the DW1000 Data Sheet [1].