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BLOCK ACKNOWLEDGEMENT MECHANISM FOR SPEEDING UP NODE-TO-NODE TRAFFIC IN LOW-POWER AND LOSSY NETWORKS

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ABSTRACT

The Wireless Smart Utility Network (Wi-SUN) Alliance promotes interoperability for large scale wireless mesh networks (WMNs). Such Low-Power and Lossy Networks (LLNs) are widely used in industrial Internet of Things (IoT) settings. In order to improve throughput in node-to-node (N2N) communications for Wi-SUN based wireless nodes, techniques are presented herein that support the addition of a Block Acknowledgement (BA) mechanism to the Wi-SUN protocol. Such a mechanism may, among other things, eliminate a significant acknowledgement (ACK) confirmation overhead when a pair of nodes are using an Extended Directional Frame Exchange (EDFE) mode or an Adaptive Modulation (AM) mode to overcome radio interference.

DETAILED DESCRIPTION

The Wi-SUN Alliance promotes interoperability for large scale WMNs. Such LLNs are widely used in industrial IoT settings, such as, for example, Advantaged Metering Infrastructure (AMI) environments and Distributed Automation (DA) products. Such networks may employ the Institute of Electrical and Electronics Engineers (IEEE) technical standard 802.15.4 as their Media Access Control (MAC) layer protocol and the Routing Protocol for LLN (RPL) as their routing strategy to establish a multi-hop wireless network. In order to overcome radio interference and the multipath effect among neighboring nodes, the Wi-SUN protocol adopts a frequency hopping/channel hopping mechanism when nodes are communicating.

Because of the changeable signal-to-noise ratio (SNR) environment, link quality may not be sufficiently stable for N2N communication resulting in a potential congestion risk to an originator as they continue to unsuccessfully transmit data in order to exhaust their buffers. Therefore, it is desirable for the originator to send traffic to the recipient as soon as possible. In general there are two ways to speed up N2N communication:

- EDFE mode. EDFE is based on the American National Standards Institute (ANSI)/Telecommunications Industry Association (TIA) specification 4957.200 and is used for extending a specific channel to transmit numerous packets between an originator and a recipient. There are four examples that are included – (1) a qualified frame exchange, (2) a multi-packet frame exchange, (3) a frame exchange with initial data, and (4) a bi-directional frame exchange. Aspects of the techniques that are presented herein discuss the multi-packet frame exchange case.
- AM mode. When the wireless channel suffers from significant attenuation or noise interference, which results in a higher packet loss rate, the relevant nodes may switch to a lower data rate format to guarantee valid communication service. If channel quality subsequently improves, the data rate may go back up to the original value.

Additionally, a recipient cannot communicate with other nodes when it is receiving packets from an originator in EDFE or AM mode, and the originator is not reachable by other nodes when it is transmitting in EDFE or AM mode. Therefore, if a node spends an extended period of time in EDFE or AM mode it will negatively influence network stability because it is not connected by other neighbors.

Aspects of the techniques presented herein shorten the duration of a EDFE or AM mode period in N2N communication by compressing multiple acknowledgement (ACK) frames (see Figure 1, below) by leveraging a BA mechanism from Wi-Fi wireless network protocols into the Wi-SUN protocol.

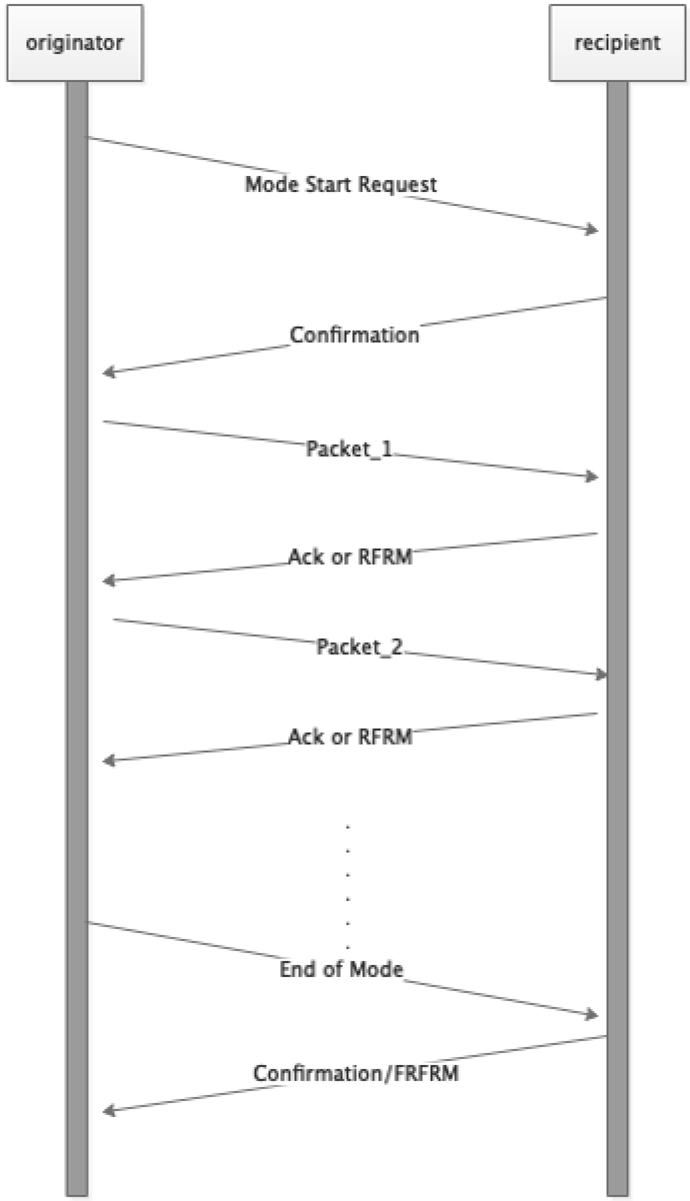


Figure 1: Multiple ACKs in N2N Communication Using EDFE or AM Mode

Aspects of the techniques presented herein import a BA mechanism into the Wi-SUN protocol (in support of, for example, multi-hop WMNs) when a node is in N2N communication using, for example, EDFE or AM mode.

Typically a BA contains three parts – (a) setup, (b) data and BA, and (c) teardown. Correspondingly, a BA for N2N communication according to aspects of the techniques presented herein also contains three such parts.

Aspects of the techniques presented herein contain a first setup part. In a Wi-Fi situation a transmit (Tx) station (STA) (e.g., an originator) first checks whether the intended recipient STA is capable of participating in a BA mechanism by discovering and examining its field (e.g., Delayed or Immediate BA capability bits). If the intended recipient STA is capable of participating, the originator sends an add BA (ADDBA) Request frame indicating the traffic identifier (TID) for which the BA is being established.

The recipient STA responds with an ADDBA Response frame. The recipient STA has the option of accepting or rejecting the request. When the recipient STA accepts the request, then a BA agreement exists between the originator and recipient. See Figure 2, below.

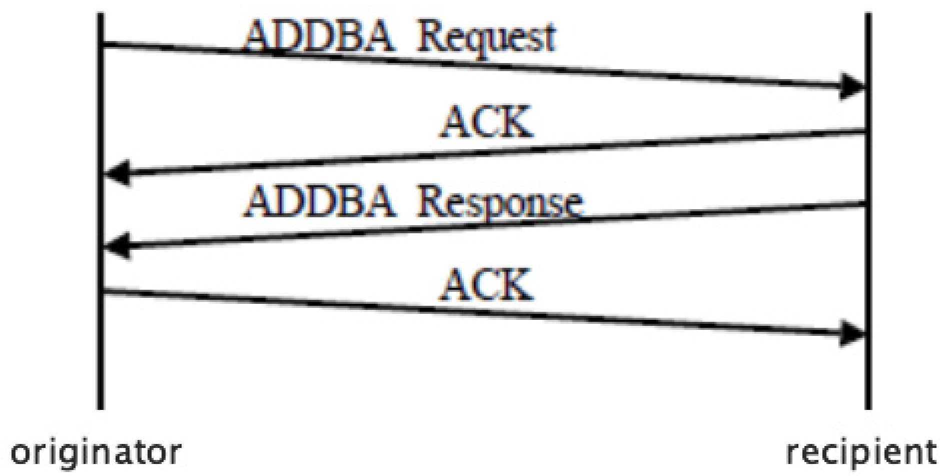


Figure 2: BA Mechanism Setup

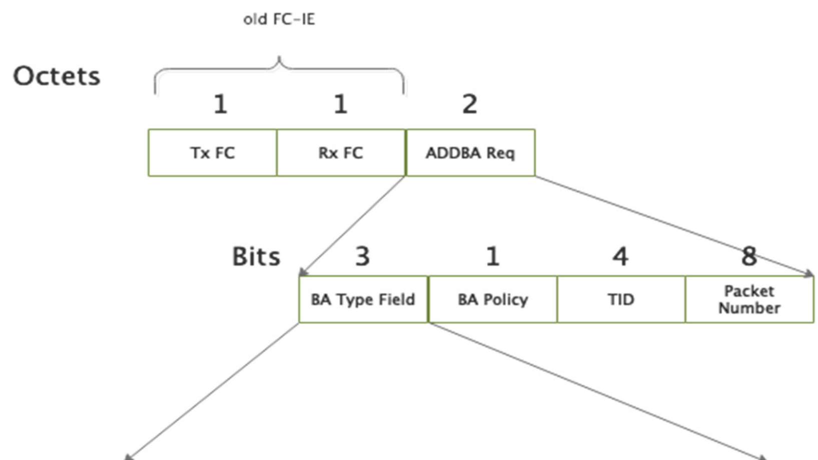
In Wi-SUN-like multi-hop WMNs, aspects of the techniques presented herein integrate both the ADDBA Request and the ADDBA Response into the EDFE/AM setup packets.

In EDFE communications, an originator needs to first send a EDFE request to a recipient carrying Flow Control (FC) Information Element (IE) (FC-IE) bits (defined by the Wi-SUN specification) as an Initial Frame (IFRM). As long as the recipient accepts the request, it replies to the originator with a Response Frame (RFRM). According to aspects of the techniques presented herein an ADDBA Request and ADDBA Response may be injected into those frames.

As described in the Wi-SUN specification, an EDFE's FC-IE "provides bidirectional flow control supporting the Extended Directed Frame Exchange pattern …" and, among other things, contains a Content field that supports two eight bit unsigned integer values:

- A Transmit (e.g., Tx) FC containing the duration, in milliseconds, of the next EDFE Response frame to be sent by the transmitting node.
- A Receive (e.g., Rx) FC containing the time allowed, in milliseconds, by the transmitting node for reception of the subsequent EDFE Response frame.

According to aspects of the techniques presented herein an ADDBA Request may be appended to a IFRM, as depicted in Figure 3, below.



BA Type Field	Detailed Description
000	ADDBA request
001	ADDBA response
010	BA request
011	BA response
100	DELBA request
101	DELBA response

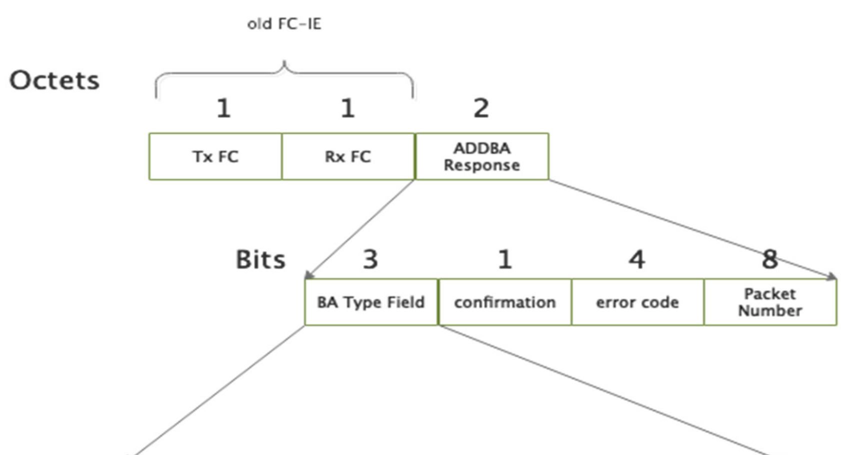
Figure 3: ADDBA Request

As depicted in Figure 3, above, the field "ADDBA Request" may be appended as a tail of a IFRM and include the following elements:

- BA Type Field. A value identifying the six possible types of BA frames.

- BA Policy. There are two policies possible for BA. A zero (0) in this field denotes an immediate BA and a one (1) in this field denotes a delayed BA.
- TID: The traffic identifier.
- Packet Number. An indication of how many packets will be sent from the originator. The recipient needs to prepare enough buffers for those packets. For example, if this field contains the value 10 then the recipient will check whether the available buffers (each buffer having a length equal to the maximum transmission unit (MTU) minus 2048 bytes according to the Wi-SUN standard) is larger than 10.

The recipient replies to the originator with an ADDBA Response containing the elements depicted in Figure 4, below.



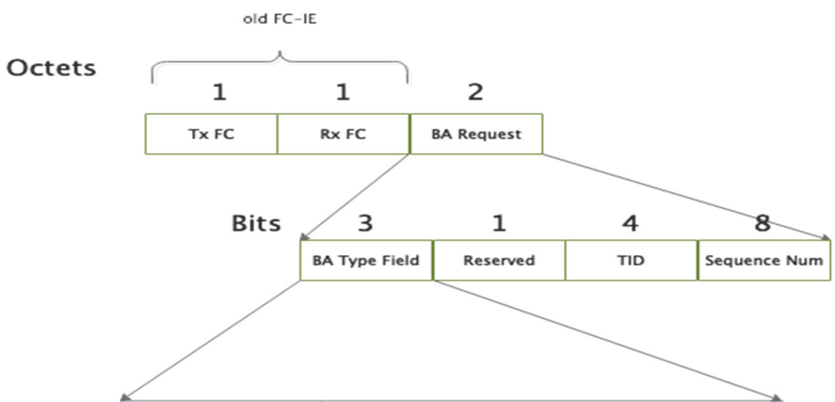
BA Type Field	Detailed Description
000	ADDBA request
001	ADDBA response
010	BA request
011	BA response
100	DELBA request
101	DELBA response

Figure 4: ADDBA Response

As illustrated in Figure 4, above, the recipient replies to the originator with an ADDBA Response containing the following elements:

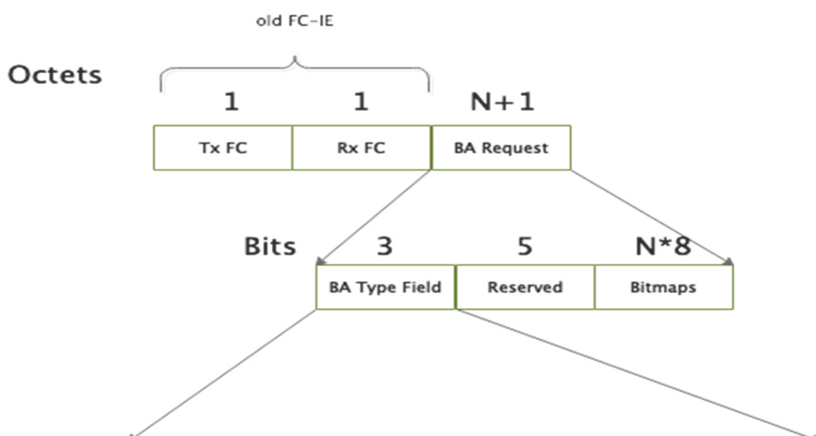
- BA Type Field. As with Figure 3, above, a value identifying the six possible types of BA frames.
- Confirmation. A zero (0) in this field indicates that this "ADDBA request" is (totally or conditionally) accepted by the recipient. A one (1) in this field indicates a rejection.
- Error Code. A value giving the detailed reasons for any rejection.
- Packet Number. If this field is non-zero and the confirmation field is zero (0) then it means conditional approval for the recipient. For example, an originator wants to continuously send 64 packets but it is not sure whether the recipient has enough idle buffers to support that transmission. Thus the originator starts an "ADDBA request" with a delayed (or split phase) BA policy where the "BA policy" field is one (1) and the "Packet Number" field is 64. When the recipient receives this "ADDBA request" it detects that its available buffers are only 10, so it will conditionally confirm this request and set the "confirmation" field to zero (0) and the Packet Number field to 10 in its "ADDBA response".

Under further aspects of the techniques presented herein during a second data and BA part, the originator may transmit a block of Quality of Service (QoS) data frames to the recipient (in order to know which frames may have been missed during communication), the originator will send a BA request to the recipient, and then the recipient will reply with a BA response to the originator. See Figures 5 and 6, below.



BA Type Field	Detailed Description
000	ADDBA request
001	ADDBA response
010	BA request
011	BA response
100	DELBA request
101	DELBA response

Figure 5: BA Request



BA Type Field	Detailed Description
000	ADDBA request
001	ADDBA response
010	BA request
011	BA response
100	DELBA request
101	DELBA response

Figure 6: BA Response

Various of the parameters that were depicted in Figures 5 and 6, above, include:

- BA Type Field. As with Figures 3 and 4, above, a value identifying the six possible types of BA frames.
- TID: The traffic identifier.
- Sequence Num. The sequence number for each block packet.
- Bitmap. A sequence of bits where each bit represents a packet according to the Sequence Num. If the corresponding packet is received, the bit will be set to one (1), otherwise the bit will be set to zero (0).

As noted previously, there are two policies possible for using BA -- immediate BA and delayed BA.

Under an immediate BA policy the originator requests an acknowledgement bitmap of outstanding QoS data frames by sending a BA request frame, the recipient maintains a BA bitmap for the block and immediately replies to BA request with this bitmap. The originator checks the returned BA bitmap and if some frames have failed the originator will re-transmit these packets with either a normal method (e.g., per packet per ack) or a BA method. See Figure 7, below.

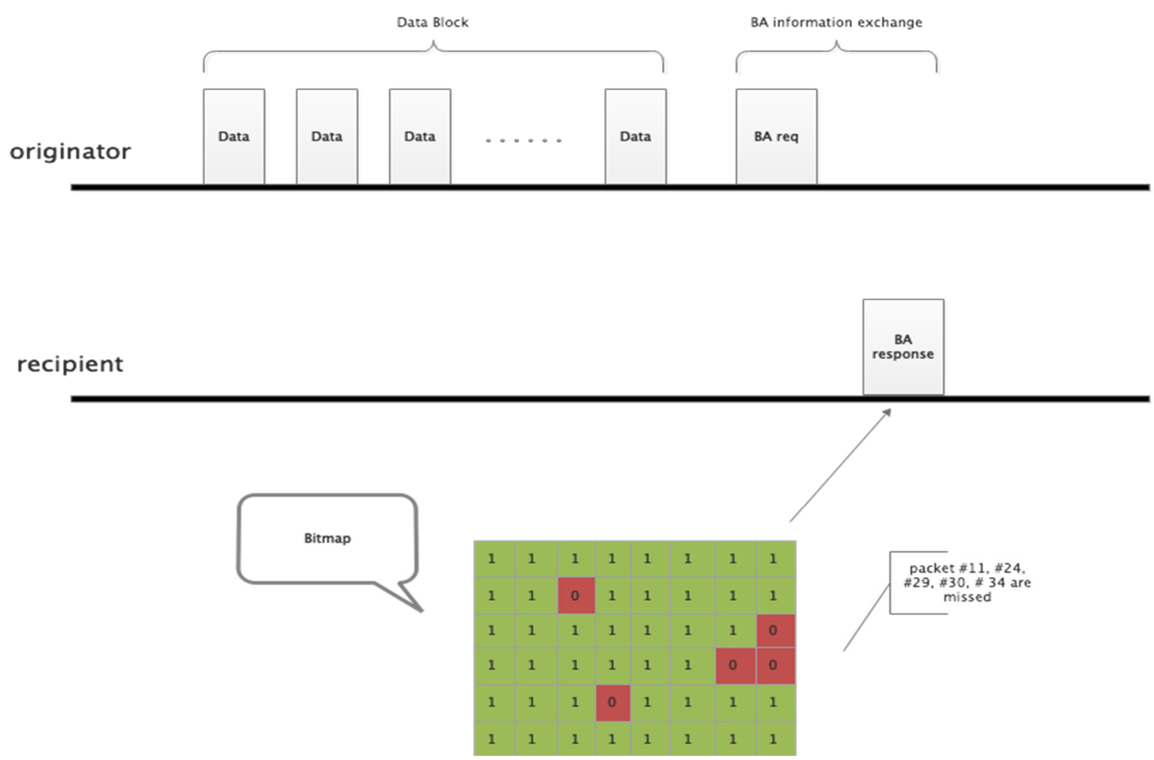


Figure 7: Immediate BA Exchange

An alternative to the immediate BA policy that was described above is a delayed BA or split phase BA policy, as shown in Figure 8, below. In general, the nodes of a Wi-SUN/CG-Mesh are resource constrained, thus the available buffers are usually not sufficient to receive all of the packets from the originator. For example, if the originator sends an "ADDBA request" with a delayed BA policy and total packet numbers, the recipient will reply with an "ADDBA response" with the maximum acceptable packet numbers. So, the total BA progression will be split into several rounds with the originator sending a "BA request" at the end of last BA session. During the interval between two rounds of a BA session the recipient could forward existing packets to its preferred parents to clear used buffers so that it could have idle buffers for the BA session's next round.

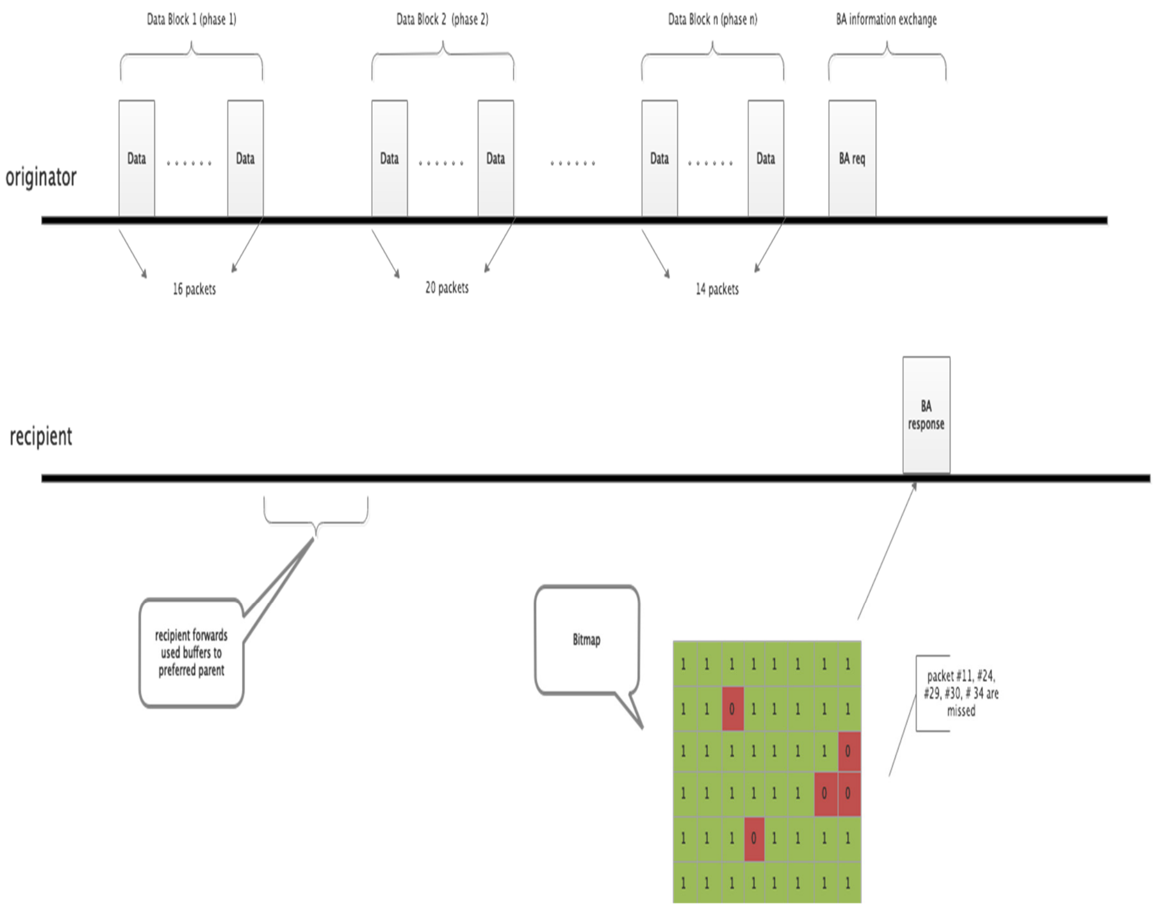
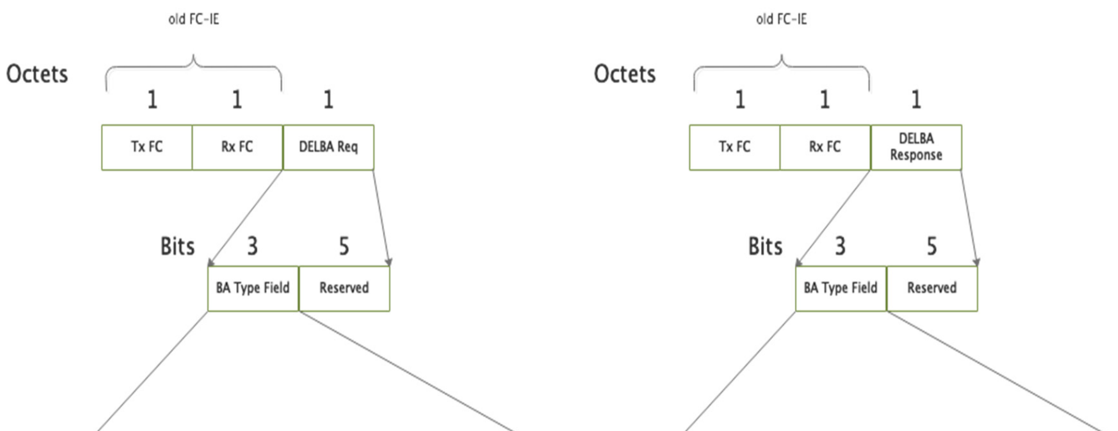


Figure 8: Delayed BA Exchange

The bitmap reports the statistics of the same TID thus the recipient needs to maintain a table for the same TID. In addition, each sub-block requires a Setup operation (as described previously) before the originator sends data, which means each phase requires an "ADDBA request" and "ADDBA response" exchange in advance. It is important to note that the recipient could reply with the currently available maximum buffers to the originator, so each sub-block could have a different count for the number of transmitting packets.

Under further aspects of the techniques presented herein and similar to the setup stage, a third teardown part encompasses appending a "DELBA request" as the tail of last RFRM for the originator and a "DELBA response" as the tail of FRFRM for the recipient, as shown in Figure 9, below. This exchange denotes the end of the whole BA progress.



BA Type Field	Detailed Description
000	ADDBA request
001	ADDBA response
010	BA request
011	BA response
100	DELBA request
101	DELBA response

BA Type Field	Detailed Description
000	ADDBA request
001	ADDBA response
010	BA request
011	BA response
100	DELBA request
101	DELBA response

Figure 9: DELBA Exchange

The techniques that are presented herein, aspects of which have been illustrated and described above, may be further explicated with reference to two hypothetical examples, each example including a different BA policy.

A first hypothetical example includes an immediate BA policy. Aspects of this example are presented in Figure 10, below.

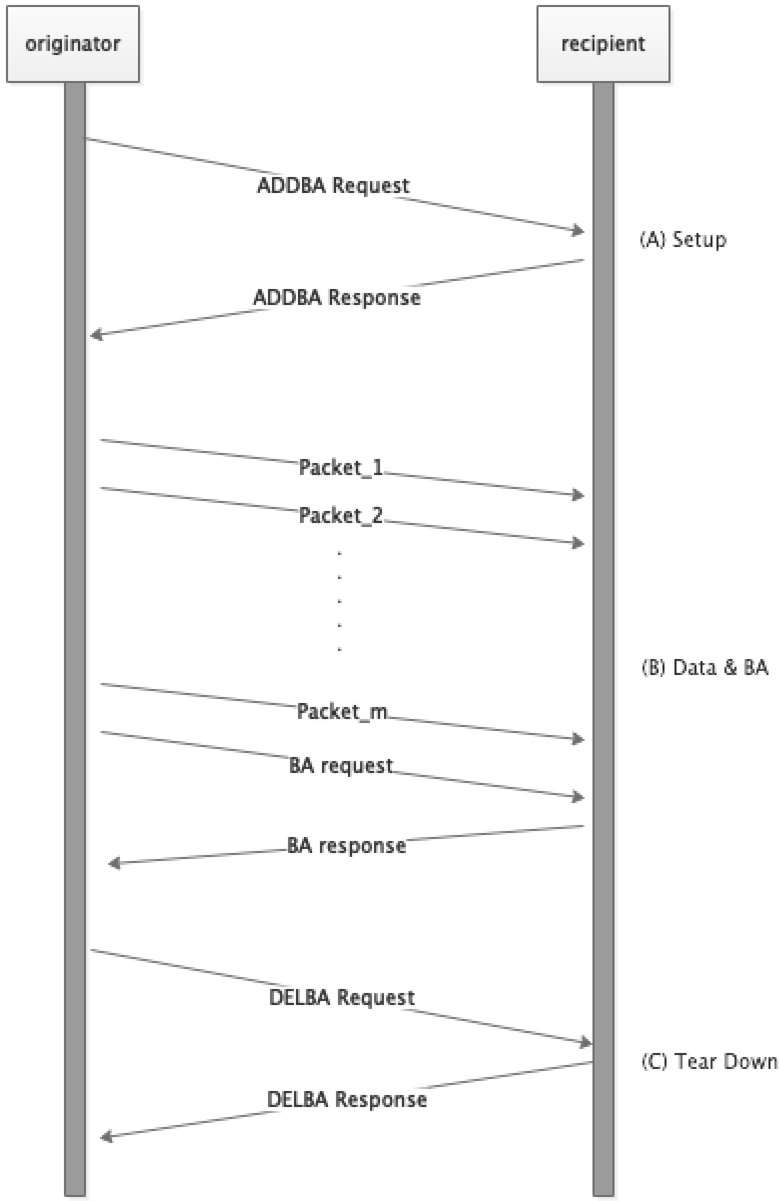


Figure 10: Immediate BA Example

A second hypothetical example includes a delayed BA policy. Aspects of this example are presented in Figure 11, below.

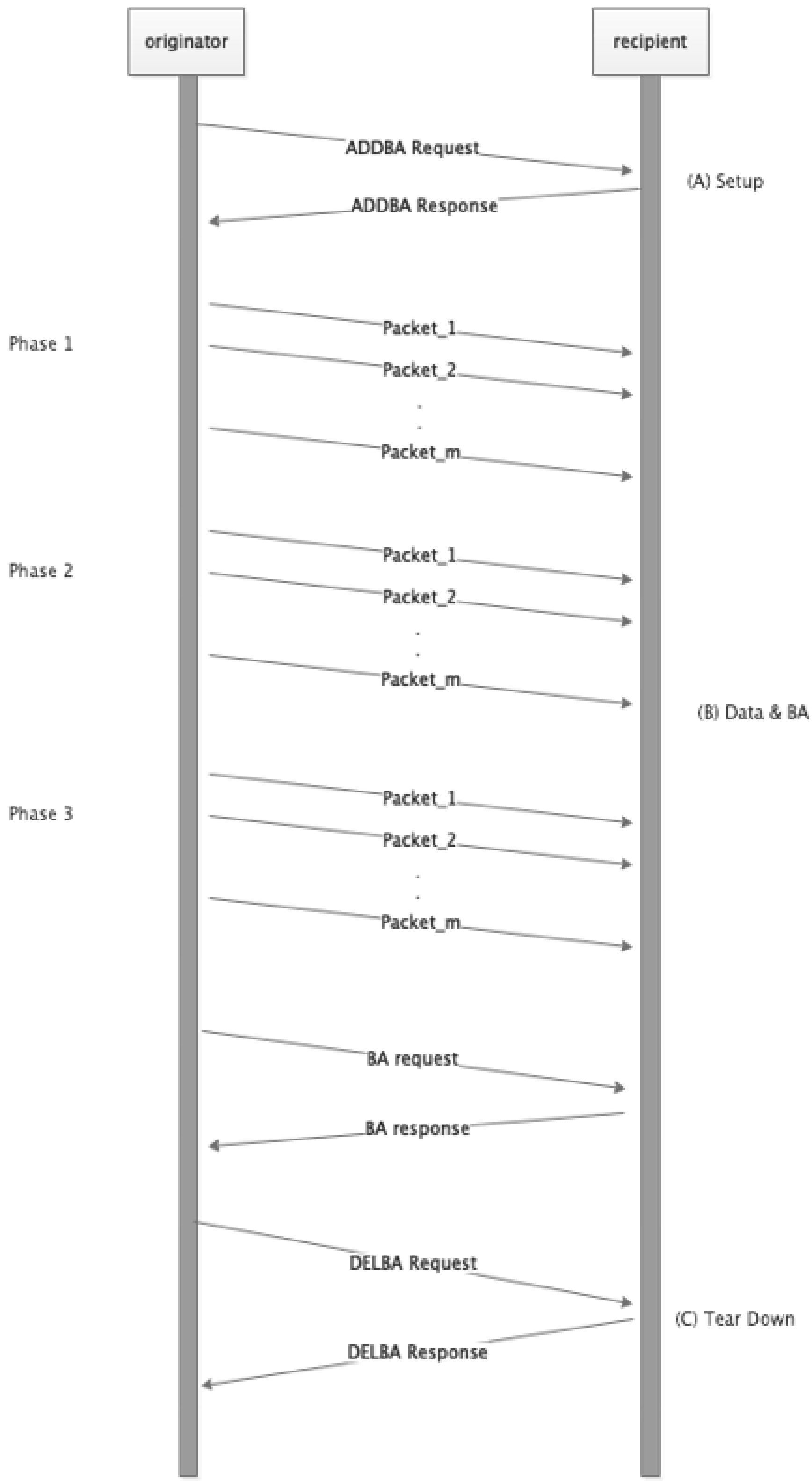


Figure 11: Delayed BA Example

In summary, techniques have been presented that incorporate a BA mechanism into wireless mesh networks (e.g., RPL-based LLNs) for optimizing N2N traffic with EDFE mode and AM mode. Under aspects of the presented techniques BA information may be attached as a tail to a EDFE or AM frame, such as an FC-IE. Alternatively, the BA information may also be an independent IE (e.g., a BA IE) for the Wi-SUN protocol. Further under other aspects of the presented techniques, a split phase BA mechanism may be employed for resource constrained devices in LLNs, which may support the efficient re-use of buffers and save acknowledgement overheads in high volumes of N2N traffic communication. Thus, the techniques presented herein may provide a good supplement to the Wi-SUN protocol.