ECEN 5823-001
Internet of Things Embedded Firmware

Lecture #23

13 November 2018

Be Boulder.

University of Colorado Boulder

Agenda

- Class Announcements
- Reading Assignment
- Project Update feedback
- Project Update #2
- Quiz 10 review
- Bluetooth Mesh

Class Announcements

- Course project update 2 is due Tuesday, November 27th at 11:59pm
- Fall Break starts next week!

What I have learned from Silicon Labs

- With the GATT messages using the GATT bearer, can these messages span the mesh network or are they limited to direct connect nodes similar to Bluetooth Smart?
  - Unicast can be transferred via GATT or ADV bearer, GATT bearer is typically used for the proxy connection, and a GATT bearer message can be relay to the whole network via its proxy node which could use the ADV bearer.

What I have learned from Silicon Labs

- On a published message with acknowledgment in Bluetooth mesh, if a single subscriber acknowledges, does that fulfill the acknowledgement of the message and all the other subscribers will then not send an acknowledgement? Or, if a publisher has a 100 subscribers, then 100 acknowledgements would be sent/received?
  - This operation is left for the user to decide in our SDK, when you send a message with response needed, then on the receiver side, you can see the corresponding bit is set in the received event, you can use the api command to send ack back. It's not defined by the SPEC nor silicon vendors, but note if 100 subscribers send ack back, it will be a big flood for the network.

Reading Assignment

ECEN5023-001 – Reading List
Internet of Things Embedded Firmware
Week 12

There is no quiz on this reading, but material from these readings will be on the final exam!

1. "Thread Stack Fundamentals – V2 public
    a. Can be found on course Canvas weekly reading assignment folder

2. "Thread Battery Operated Devices"
    a. Can be found on course Canvas weekly reading assignment folder

Project Update #1

- What I was looking for:
  - Flow Chart
  - APIs in Flow Chart
  - Persistent Data
  - Updated schedule with what has been accomplished
  - Validation plan
    - Persistent Data
    - Communication bus working
    - Sensor data validated
    - Client/server/friend/low power/provisioning
    - Mesh
      - Hoping
      - Addressing modes
    - BLE
      - ConnInterval/Slave Latency
      - Low Power operation

Project Update #2

ECEN 5823
Project Update #2 Assignment
Fall 2018

Objective: To update the status and state the project functionality that will graded based on.

Note: You can use your course project update #1 as a base for this project update #2.

Project Proposal Due Date: Tuesday, November 27th, at 11:59pm via Canvas drop box

Team proposals: (Include and Provide update to the below items)

1. Describe what problem this project addresses
2. How does this project alleviate or solve the problem?
3. Functional block diagram of the team project
4. Summary of each individual project and how it plays a role in solving the problem
5. Project team members
6. Team project validation plan

Quiz 10 review

In Bluetooth Mesh, the _____ field in a state transition message is used to synchronize action between multiple receivers.

Quiz 10 review

List the three message addressing modes of Bluetooth Mesh _____ , _____ ,

_____

Quiz 10 review

In Bluetooth Mesh, Sensor State is a composite of four states. List these four states:

Quiz 10 review

Match the definition to its term for Bluetooth Mesh

Transition Time	[Choose]
Initial State	[Choose]
Present State	[Choose]
Target State	[Choose]
Delay Time	[Choose]

Quiz 10 review

In Bluetooth Mesh, replay protection is achieved by using _____ which the nodes keep track of based on source addresses.

Quiz 10 review

The only fields of a Bluetooth Mesh that is sent via plaintext are the _____ and _____

.

Quiz 10 review

List the two methods that Bluetooth Mesh uses to prevent its flooding mesh from infinite re-transmissions.

Quiz 10 review

In Bluetooth Mesh, for the receiver to understand what operation and what to execute the operation should be performed on, the receiving message must decode the fields _____ and _____ .

Quiz 10 review

In Bluetooth Mesh, relay nodes only forward messages which have a TTL value greater than 0. True or False

- True
- False

Quiz 10 review

In Bluetooth Mesh, a state change that results in another state change are said to be _____ states.

Quiz 10 review

In Bluetooth Mesh, a Friend can receive a message on behalf of a defined Low Power node and will acknowledge the message with an _____ acknowledgement.

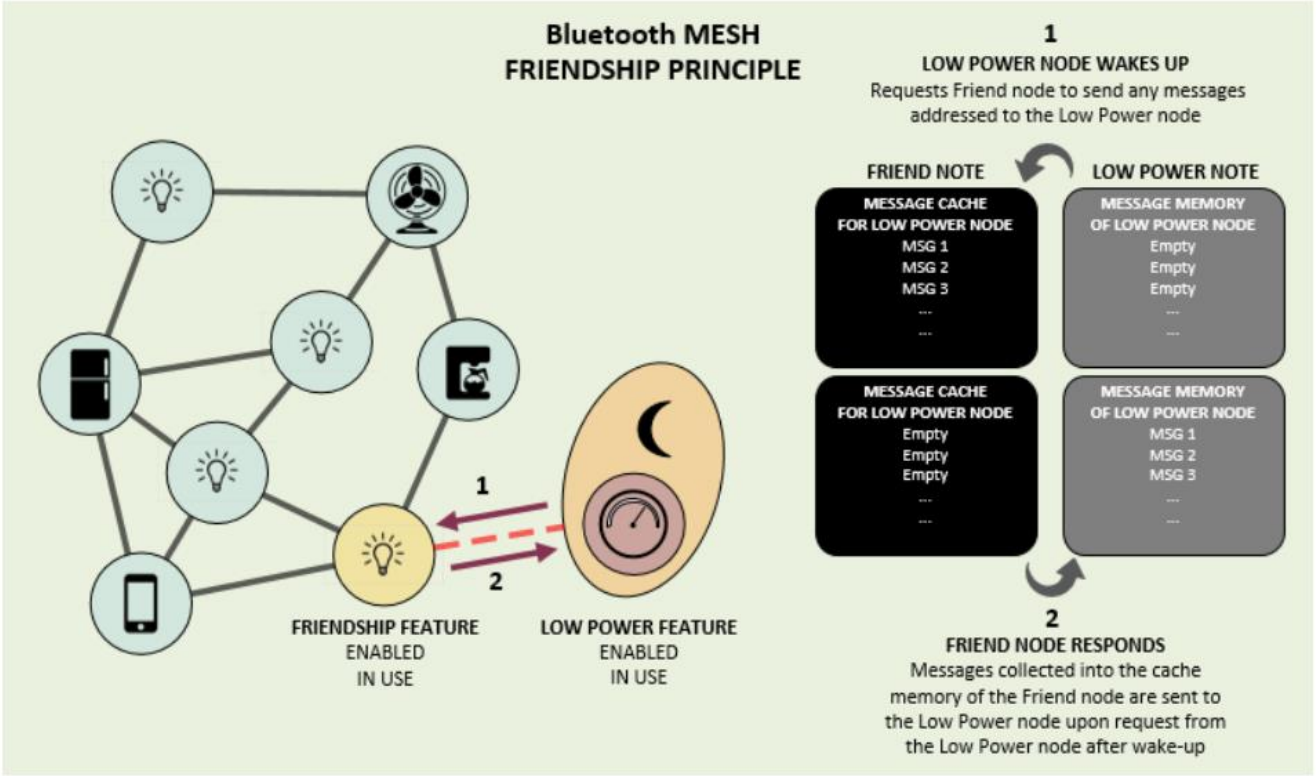
Quiz 10 review

In Bluetooth Mesh, [ ] addresses are used to address a single element in a node while

[ ] addresses are used addressing multiple elements in one or more nodes.

Bluetooth Mesh: Friendship

- Friendship is based on polling and there are some timing parameters defined at the setup of a Friendship connection which then are static until the connection is finally (if ever) cleared
- It should be noted that the Friendship device's power consumption may increase when messages are received acknowledged and stored and finally sent to the Low Power node



Relationship between a Low Power feature node and a Friend node.

Bluetooth Mesh: Sensor Cadence

- The user can configure the sensor to send measurement values as the value changes either up or down by more than a configurable delta value
- This feature saves energy since the sensor can be configured to report only when a value changes more than the configured delta value
- A more refined way of controlling how the sensor reports value changes is provided by Sensor Cadence state which controls when and how often the sensor reports using Sensor Status messages
- This state can be used to configure the sensor to send updated measurement values more often when the value changes more rapidly and vice versa
- The application can then be programmed to note the speed at which the value increases or decreases

Bluetooth Mesh: Lighting Control

- The simplest control method is related to turning a light source on or off or dimming a light
- For tunable white light sources the color temperature can be controlled by setting the actual color temperature value referenced to the black body curve together with a setting determining the set point distance from the black body curve
- In case the light type allows color changing in all three dimensions (hue, saturation and lightness) it is possible to set all three values independently

Bluetooth Mesh: Lighting Control

- The default model for color light control with mesh networks is generally based on the so called HSL (Hue, Saturation, Light) model instead of the RGB model typically used with computer monitors and printers
- If desired the HSL color space can be converted to e.g. RGB
- For professional lighting applications colors seen by the human eye are often represented using coordinates (x, y and Y) as defined in a color chart
- The coordinates of the color on the chart are defined by x and y whereas Y defines the luminance
- In mesh networks an xyL system is used instead where L corresponds to perceived lightness
- To enable accurate “fine-tuning” of a color source all light control states have 16-bit precision.

Bluetooth Mesh: General Location

- For widely dispersed mesh networks and/or networks with a multitude of sensors and other devices the location of
- any particular device is often mandatory information required by many applications
- Bluetooth mesh provides a generic state called Generic Location, which can be used to define the location of each device accurately
- Global Latitude and Global Longitude fields determine the coordinates (WGS84) of the device
- Global Altitude determines the altitude of the device above the WGS84 datum.

Bluetooth Mesh: General Location

- Local North and Local East fields can be used to describe the location of the device with reference to a local coordinate system on a predefined map with Local Altitude giving the altitude relative to the Generic Location
- There is even a Floor Number field which determines the floor on which the device is installed in.
- For devices which might be moved or move autonomously the Uncertainty field provides a way of defining that the device is either stationary or mobile

Bluetooth Mesh: Time and Scheduler

- Knowledge of time is the basis of scheduled and timed actions such as delayed switching or adjustment of certain settings linearly from an initial state to an end state in the defined time period etc
- However, what is also needed is the capability to store and recall device states when needed
  - Does this sound like Bluetooth Low Energy?
- The basis of time in Bluetooth mesh is the International Atomic Time (TAI) represented as seconds after 00:00:00 on 2000-01-01
- This information is passed on to all nodes in the network as long as one node has the time information

Bluetooth Mesh: Time and Scheduler

- States can be changed autonomously according to a programmed schedule based on the UTC time and an ISO 8601 calendar
- A register provides the means to set the time points at which a change of state is to be carried out

Bluetooth Mesh: Preventing Mesh Saturation

- Bluetooth mesh is based on flooding which is typically simple to implement but presents some issues regarding scalability as the network size and/or amount of traffic increases
- In flooding messages injected into the mesh network are potentially forwarded by all relays nodes which receive the message
- This may cause infinite retransmissions which will cause the mesh network to saturate
- Bluetooth mesh provides two methods, message caching and the Time-to-Live (TTL), to prevent the endless forwarding of messagesin the mesh.

Bluetooth Mesh: Preventing Mesh Saturation

- Network cache method
  - is designed to prevent forwarding of messages already received by the node
  - The node compares the received message to already stored messages in it's network layer cache
  - If the message has already been received the message is discarded
  - If the received message is new and intended for the receiving node it forwards the message to the higher architectural layers of the software in the node
  - If not the node simply relays the message forward to other nodes
  - List size is determined by the implementation

Bluetooth Mesh: Preventing Mesh Saturation

- Each message also includes a Time-to-Live (TTL) number
  - This number is originally determined by the source node but initially is assumed to be 64 (maximum value is 127)
  - TTL number limits the number of forwards allowed for that particular message
  - A node which forwards the said message also decrements the TTL value by one
  - Relay nodes forward only messages which have TTL values larger than 1
  - Thus the “lifetime” of a forwarded message as it hops along in the network can be effectively limited

Bluetooth Mesh: Monitoring Heartbeats

- Heartbeat messages can be used for checking whether a node is still active and for determining the distance to a node
- Heartbeat messages can be configured to be sent periodically a limited number of times or infinitely
- The destination address must be configured
- Received Heartbeat messages can be counted and the results are indicative of reliability
- Heartbeat messages also carry the TTL (Time-to-Live) value so that the number of retransmissions (hops) which can also be used to analyze reliability.
- This feature makes it possible to tune the TTL value to its optimal setting.

Bluetooth Mesh: Service Ratio

- When discussing mesh networks one of the most important factors determining performance is the service ratio
- Service ratio is the ratio of transmitted packets reaching their end destinations compared to the number of all transmitted packets
- Another important factor is Application layer packet delay
- Adding relays increases performance only to a certain point after which the mesh network will start to congest especially with high traffic densities
- Usually the more packets delivered successfully during the first or second hop the better

Bluetooth Mesh: Service Ratio

- One of the bottlenecks in Bluetooth mesh networks is related to the "first hop"
  - i.e. the injection of messages into the mesh in the first place
  - After a node has been able to inject the message into the mesh the nearby nodes are most likely able to send the message further on through the mesh because there are typically several paths available
- One method to help maximize performance is randomized advertising which can improve the service ratio even further.

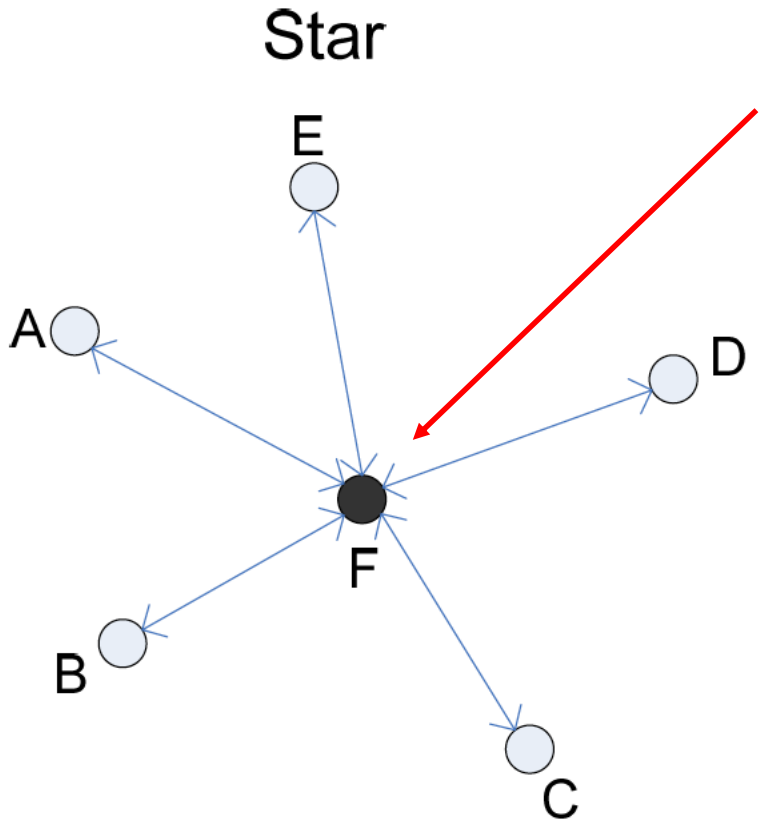
Bluetooth Mesh: Summary

- Perhaps the most important technical points defined by the Bluetooth mesh specification are related to its security related features.
  - Separate network and application level encryption makes it possible to manage overlapping networks and overlapping applications
- Easy configurability of nodes through the subscribe-publish mechanism provides ease-of-use useful in end-user applications
- The inclusion of the GATT Bearer making it possible to use older Bluetooth devices as part of Bluetooth mesh networks will certainly speed up the adaptation of Bluetooth mesh technology
- Bluetooth mesh is by definition the most secure Bluetooth standard introduced so far and provides efficient security features for IoT applications


Turning Ideas
Into Real
0:04 / 4:06

Wireless Networks

- Infrastructure networks provide typically these functions
  - Bridge to other networks
  - Forwarding functions
  - Medium access control
- In Infrastructure Networks, communications typically goes from wireless nodes to a wireless access point
  - Star Network



The Network Coordinator provides the typical functions of the Infrastructure Network

- Bridge to other networks
- Forwarding functions
- Medium access control

Star Network from AMX ZigBee white paper

Network Node

Network Coordinator