802.11 practical improvements using low power technology

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Abstract

The reliability and performance of WiFi need optimization because of the rising number of WiFi users day by day. A highlighted point is saving power while transmitting and receiving packets using WiFi devices. Wake-on–Wlan (WoW) is also implemented to improve energy consumption, but it also needs betterment. This paper will introduce universal ideas to transmit and receive packets using low-power technology like Bluetooth or BLE (Bluetooth low energy). While looking for power-saving ways in this research, WiFi connection and maintenance also take care using lesser power-consuming technology. Identifying different use-cases where low power technology can help save energy and maintain 802.11 connection is part of the research. In addition, the proposed method discuss energy saving with unicast and broadcast/multicast data. Calculation of power-saving and comparison with standalone WiFi usage clearly shows the effectiveness of the proposed method.

Keywords: WiFi, Low power technologies, Power-save, Bluetooth/BLE, Wake on Wireless Lan, DHCP, Mesh Network, Congestion

1. Introduction

With the increased demand for WiFi in today's scenario, it is essential to take care of power consumption while maintaining connections with access points. With the increased number of smartphones/IoT devices, it is needed that they should be power savvy [1]. User experience may deteriorate by getting disconnected while battery downfall [2]. IEEE 802.11 specification [3] introduced a WLAN power saver for conserving energy. It saves power by switching from active mode to power save mode. Along with this, Access Point buffer management [4], and Scheduling of Sleep/Wake [5] of stations was also performed in 802.11 power saving.

This paper aims to reduce embedded WiFi device power consumption, whether a standard 802.11 power save or Wake-on-Wlan (WoW) method. Moreover, while looking for power-saving ways in this research, this paper will also take care of WiFi connections and their maintenance problems using lesser power-consuming technology, i.e., Bluetooth/BLE.

Table 1. Acronyms and notations

Acronyms and notations	**Definition**
AP	Access Point
BT	Bluetooth
BLE	Bluetooth Low Energy
SSID	Service Set Identifier
STA	Station
DTIM	Delivery Traffic Indication Message
ATIM	Ad hoc Traffic Indication Message
WoW	Wake-on-WLAN
GTK	Group Transient Key
ARP	Address Resolution Protocol
MIMO	Multiple-Input Multiple-Output
DHCP	Dynamic Host Configuration Protocol
SOC	System on Chip
RSSI	Received Signal Strength Indicator

WiFi needs to follow a procedure to get authenticated and then connected. The first step will be to search all bandwidth for SSIDs to join. At the time of scanning, the client sends a probe request. The client sends the frames consisting of supported information rates and features of 802.11. MAC address, SSID, BSSID, supported rates involved in the Probe response frame transmitted via Access Points in response to the probe request. Also, the access point signal becomes more robust whenever a client is permitted to get associated in-network. After successful Association with the Access point (AP), in the case of secure AP, a 4-way Handshake performs. It initially authorizes a WiFi client and encrypts all information with access points.

Any device which can connect with WiFi Access Point (AP) can be called an STA device. To be associated with AP, the STA device needs to periodically send a frame to it. If no significant traffic goes between them, STA needs to send a keep-alive packet periodically, so AP knows STA is there and will not kick off a particular STA from its connected STA list.

When STA does not have anything to send and does not have anything from the AP side. 802.11 STA device has a technique where it manages power using an 802.11 power saving mechanism. This technique can help to save power by even not receiving any packet. When

STA wants to go into power save mode, it sets its PM (Power Management) bit in its MAC header to let AP know it is no more active. In this case, the Access point buffers all the information for the client device.

When the device becomes enabled, the Listen interval plays an important role. The device becomes inactive (in power save mode) before accessing the regular frames from Access Point. Station sleeps for that listen-interval, and Access Point accumulates the packets till that time. The energy also gets wasted when STA awakes in every DTIM Beacon, even when no packet is received.

One more useful power-saving optimization method in WiFi is available named Wake-on-WLAN (WoW). This industry-standard protocol helps awake a computer in sleep mode nearby or at a remote location. This setup needs less power to access computers, which helps save power and money. Wake-on-Wlan improvement [6,7] is also a research topic. There are some pointers which WiFi Wake on Lan follows:

- any: any triggering time, it will awake the device.
- Disconnect: in some cases, there can be a random disconnection to let the device wake up immediately.
- Magic: WiFi WoW transmits a particular byte by a client, which makes it more secure and enables Wake on WLAN and wakes up the system. The magic packet can be used as a reference for any unique frame.
- GTK-rekey-exchange: The system must wake up when this frame is fired as GTK (Group Transient Key) rekeying frame.
- ARP exchange: WoW feature also offload ARP Exchange at WoW time.

For making a real 802.11 network more efficient, the following significant issues are to be overcome:

One issue is interference, which WiFi devices face when the number of candidates increases (devices like mobiles and microwaves). If the junction volume and portability are high, channel skipping and energy requirement increase. MIMO is also introduced, which regularly expands the capacity of WiFi connection for transmitting in different networks.

It is required to optimize DHCP steps as it causes a delay in establishing setup. Using a low level of software and hardware can impact the signal strength. All this may lead to a loss in possible frequencies because of the total delay in the whole connection. WiFi device performance is critical in a noisy, congested environment or when asymmetry is present between transmit and receive traffic [8]. Sometimes, creating a connection with AP and maintaining an existing connection seems a very tough task, especially in a dense environment [9,10] like shopping malls, railway stations, or a university where so many users work on the same frequency at the same time. WiFi of STA will be still on and continuously consumes power. We will overcome this issue in this paper.

The attributes come under internet connection consisting of intelligent sensors, actuators that give complete intelligent surroundings. For the sake of easiness, these devices are wireless and battery-powered. WiFi connections look attractive, but it consumes high power, which is also a challenge to maintain a good power backup. That is why we took the help of Bluetooth or BLE (Bluetooth Low Energy), which has limited setup criteria, consumed less power, and worked on the frequency-hopping concept. Also, the Bluetooth range is expanding with improved techniques ranging from 100 to 200 meters [11], which is enough to support mostly WiFi user scenarios in a dense environment.

The rest of the paper is organized as follows: Section 2 reviews relevant work related to the wireless device power save, fast connection, and other low power methods. Section 3 discusses the architecture of the proposed method and the different use-cases of the proposed approach described in Section 4. Results and discussion are presented in section 5, and, finally, Section 6 concludes the proposed work.

2. Related Work

Several researchers work in the WiFi domain, and they are multi-dimensional. WiFi energy management via traffic isolation [12] is a challenging subject. In the Internet of Things (IoT) world, devices become very power savvy; even a minor loss of power is a significant loss for them. Also, features like FOTA (Firmware Over The Air) need a high throughput interface, but regular work needs less power consumption. The WiFi performance is much better when the transmit path is shut down [13] and pays attention in the absence of unreserved frames. Energy consumption is a third less than the receiving end compared to the transmitting end. Although traffic sample changes hugely, this will not be highly efficient for saving energy. Several previous works have investigated techniques to solve the power consumption using multiple radios [8] for battery-powered devices. Some research used WiFi with low power technology, whether BLU-FI or ZigBee attached power save [14]. Receiver design [15, 16] or context-sensitive framework development [17] is also a way to save energy.

Microsoft researchers worked on a functionality called Blu-Fi [18]. As the name tells everything, it has both WiFi and Bluetooth features. Some contact patterns of Bluetooth are used in their device to check whether WiFi is available or not. Bluetooth devices use a shallow range for an accurate forecast. Blue-Fi reduces the process of learning time for the attributes of linked WiFi.

An intelligent solution Wi-Fox [19] proposed helps reduce STAs traffic asymmetry, increases performance loss due to rate-diversity/fairness, and avoids degradation due to TCP behaviour. It increases Rx throughput by 400-700 %, reducing average response time by 30-40 %. Fast connection and power optimization are challenges in a WiFi environment at a broad level, and researchers are working to overcome these challenges. WiFi users are increasing day by day, and analysts are working on the behaviour and problems [20].

Anand & Team [20] also took some observations in dominant applications where they found that the rate of repetition is lower in the case of average and regular ones. So it can be said that by using less repetition rate, the AP's requirement will be less even when the number of users is more. The issues occurring in packets can be solved because of the high capacity of 802.11a technology. One problem is that the frequency is not equally distributed among APs. In between, the users who are accessing these APs do not have any communication. So, due to the balancing load of those APs, the formulae that get executed will not give a good performance.

Power consumption is also challenging, especially for the battery-operated device [21]. The offloading of features is performed to overcome this challenge in a small manner. Here researcher introduced the Tail Ender scheduling algorithm. More ideas are presented in each condition and real-life scenario for saving more energy. Tail Ender will work specifically on social feeding, e-mail, and net surfing. Using some information, author found the efficiency of Tail Ender with a flag scheme. As per the survey, the performance of downloading in mobile phones is 60% more than social searching, and in case of net doubts, it was found that more than 50% downloading outputs.

Researchers used caching of previous connection information [22] or did fast sub-steps like authentication [23] to make a quick connection. Pre-allocation of DHCP is also performed [24] to improve connection time. 802.11ba [25] WUR (Wake-up radio) mode is also a related work which is a low power operating mode, where only the Rx chain (WURx) is active, but still, it takes much power in comparison to BT. The research work presented in [26] proposes a deterministic power management method with dynamic LI for the Adhoc network. This paper introduces a novel APM (adaptive power management) method. This method enables the PS station to adjust its listen-interval according to its need dynamically and solves 802.11 Adhoc PSM difficulties.

The authors in [27] investigated the wake-up success probability based on-demand WiFi wake-up. A high congestion channel is chosen to perform the test. The author has shown that the wake-up success probability is improved when the number of interfering nodes is small in each channel. On the other hand, the increase in the number of interfering nodes can degrade the wake-up success probability due to the delay in transmitting wake-up frames. Here and in [28], a small radio WiFi external device is used to wake up the primary device, but WiFi still takes more power than Bluetooth. Bluetooth works on an adaptive frequency-hopping concept, so it mitigates the risk of collisions by using spread spectrum techniques. Hence our solution solved these problems in a more well manner. Survey [29] shows different low power wake-up radio, hardware, and networking topologies cover under the paper. But as described, all wake-up radio uses WiFi, and it can improve power a little bit. These all methods can help with WiFi wake-up but can't avoid unnecessary wake-up. For example, our proposed method can reduce the unnecessary wake-up due to the DTIM miss case.

The proposed method in this paper uses the concept of a combo chip (WiFi + BT). It is an amendment to existing methods or techniques. The motivation for our work is to introduce a complete power-save feature and a more practical solution to manage fairness in a noisy environment.

3. Architecture of the proposed method

This concept assumes that both WiFi and Bluetooth are presented on the same SOC (system on chip) and both radios cover the range of peer device. The SOC is a centralized hub, and most of the computer components can be present on a single base. It is a combined circuit where many different parts or elements can connect. These components consist of memory, input/output ports, and secondary storage. All chip vendors generally put WiFi BT/BLE on the same interface, as shown in **Fig. 1**. On the same SOC, both entities (WiFi and Bluetooth/BLE) can interact and share a common memory.

The below Fig. only shows the infrastructure (centralize) mode, but the same architecture can also be applicable for the Ad-hoc mode. In Ad-hoc mode, ATIM will replace the work of DTIM in infrastructure mode. Instead of AP, another WiFi device that has buffered Unicast or Multicast packets, it is announced via ATIM to other WiFi devices.

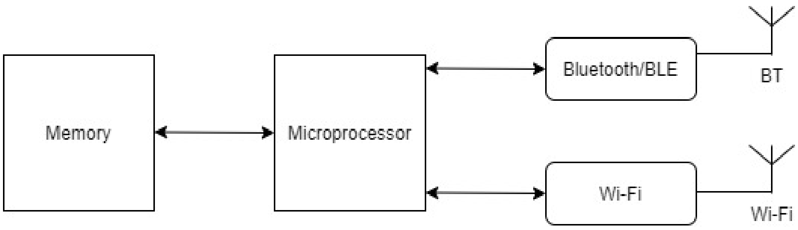

Fig. 1. WiFi & BT on the same SOC (System on chip)

3.1 Brief Description

- For transferring information between Bluetooth and WiFi, keep WiFi and

Bluetooth in the same SOC in IoT devices.

- Simultaneously make the WiFi and BT connection and exchange the data from any interface. Even BT data exchange is also possible without creating a connection.
- WiFi can go in sleep mode, active mode, or perform the required task, whenever triggered using Bluetooth, as they are connected on a single platform.
- WiFi and Bluetooth are involved in both AP and STA on the same SOC, which can help to transmit information between each other (via Software or Hardware).
- Bluetooth software can update WiFi radio's information and vice versa.

The integration of WiFi and Bluetooth is done to operate with very little energy consumption and decreased cost. The proposed method topology and connection mechanism are shown in **Fig. 2**. AP's Bluetooth radio can play the role of master for the STA's Bluetooth (slave) radio. The basic idea of the proposed method is that WiFi data can be delivered using Bluetooth or BLE interface in the following conditions:

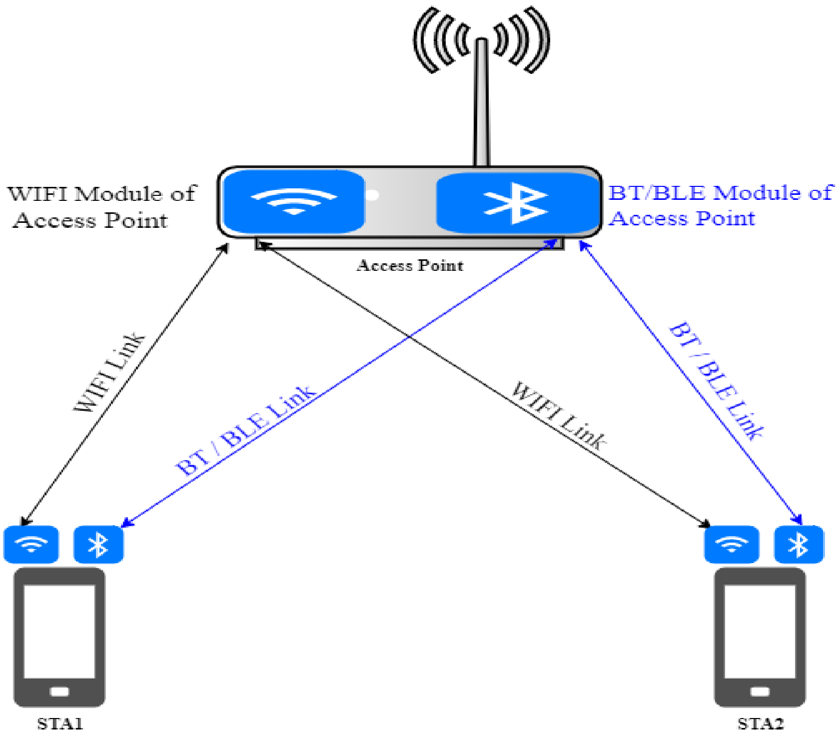

Fig. 2. Proposed Topology

- The environment is heavy noisy, so the WiFi interface cannot get a chance to transmit its packet.
- The WiFi device is in sleep mode.
- To make a fast connection and maintain it.
- Below two are the Methods that can be used to transmit WiFi packets via Bluetooth radio:
- Complete WiFi packets (Header + Payload) sent using Bluetooth radio:
  - Bluetooth physical layer adds its preliminaries.
  - A prefix is attached in the Bluetooth packet, which can tell this packet aims at

the WiFi system.

- Real WiFi packet.

WiFi packet payload under the Bluetooth packet (**Fig. 3**).

Bluetooth Preamble	Prefix	Wi-Fi Packet

Fig. 3. WiFi Packet fit into BT Payload

3.2 Methods used in Mesh Network

All devices are connected with WiFi and Bluetooth interfaces (**Fig. 4**). In a mesh topology, proposed methods can also be implemented. Mesh network is a term used for many wireless nodes, and all those nodes can communicate with each other in a very vast area. In a wireless mesh network, a single node must connect physically with the internet. Then using that single node, all other wireless nodes can connect in its sector. In this way, those nodes will again share their internet with the nearest nodes. AP position can be dynamic as well; it just needs to maintain WiFi and BT connection with STA's. It can be implementation-dependent. For example, in the EasyMesh [30] network, STA does not care with which Access point it will connect. The proposed architecture easily can fit into WiFi EasyMesh setup.

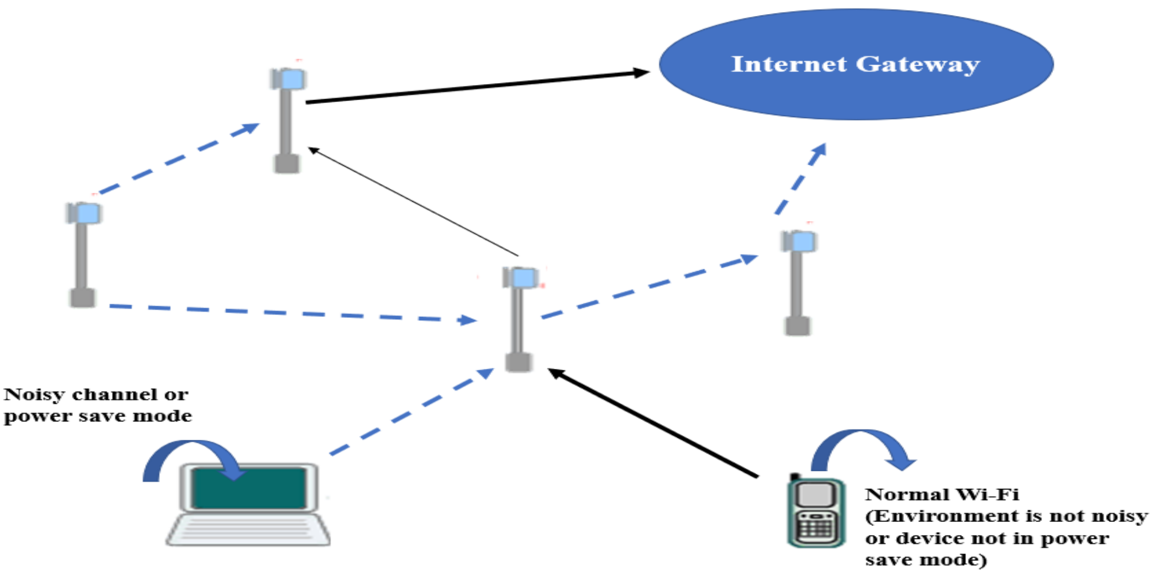

Fig. 4. Proposed Method Work on Mesh Topology

4. Proposed method works in different use-cases

Every WiFi packet (Management, Control, and Data) and many user procedures are tested using the proposed approach to identify valuable scenarios. Using Atheros ar9271 USB board system simulation [31] performed on Ubuntu Linux machine. WiFi is actual, but Bluetooth simulated utilizing an application on the same device, and after test, some important parameters (**Table 2**) determine which can help the decision.

Table 2. Decision maker parameters

Parameter	Decision
RSSI	If less than -90 dBm
Power-Save	System is in power-save mode
Retry Count	Count of 802.11 frame retry is greater than 7
Payload Size	Payload size less than 200 so it can fit into BT frame
wake-on-wlan	Wake-on-wlan feature enable or not

Here identify some user scenarios problems where the proposed method can deliver the best performance and optimize the network behavior:

4.1 Fast Connection

The connection of WiFi is a necessary process. In typical scenarios, everyone will notice the time required for a WiFi connection and the possibility of the success rate of connection.

4.1.1 Problem Statement

Scanning, key exchange, DHCP negotiation, and Authentication make the WiFi process longer. DHCP process, if happening repeatedly, can cause some good loss of time from the 802.11 STA connection point of view [32,33].

4.1.2 Solution

The first connection step is scanning for the desired AP (Access Point) via an STA device. When STA finds its AP, it will initiate the Authentication process. If STA does not support static IP address (mostly time it does not support), DHCP procedure can offload to Bluetooth/BLE interface. WiFi MAC address and other DHCP desired data given to the BT entity. So, after scanning simultaneously, both interfaces will play their role, the device's WiFi radio transmits authenticated packets, and the Bluetooth radio will send DHCP packets to AP.

4.1.3 Details

- Usually, BT/BLE exchange of packets can also be possible without link manager connection. However, there should always be radio and baseband link between STA's and AP's BT peers.
- Once STA WiFi aims to get linked with AP after the scan, it transmits the Auth request. Simultaneously, DHCP settlement also gets started between AP's BT entity and STA's BT entity.
- So, four packets, i.e., Authentication Request, Authentication Response, Association Request, and Association Response, are taken care of by the WiFi entity and
- Four DHCP packets, Discover, Offer, Request, and Acceptance (DORA), will be taken care of by BT/BLE entity.
- After completion of the DHCP settlement, the BT entity on the STA end shares the DHCP result (IP address or failure reason) with the WiFi entity of STA.
- If a WiFi connection failed for some reason (Authentication or Association failure), and DHCP got a pass, WiFi Entity can discard the BT message.

In **Fig. 5**, the black arrow signifies data through a WiFi radio, and blue dashed arrows show data through Bluetooth/BLE radio. The same color convention will follow in other upcoming figures.

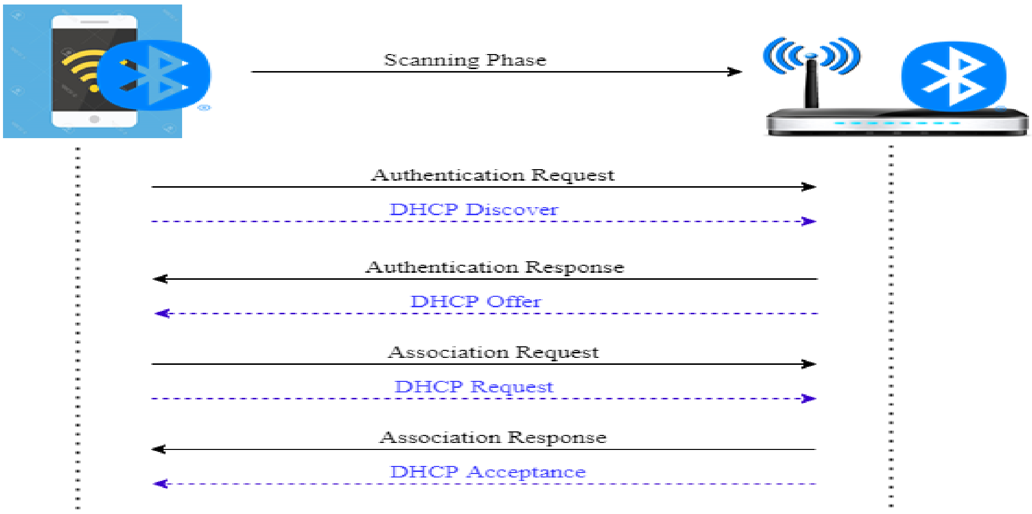

Fig. 5. WiFi Performing Authentication/Association while BT Entity performing DHCP exchange

4.2 Maintain connection in a highly congested environment

Maintaining an already created connection will become more critical with the increasing demand. WiFi devices at Client-end have less power to transmit than the access point. RSSI value impacts keep-alive time [34]. An alive packet is sent to AP when the client device has no significant transmission between device and AP to prolong connection without fail with the access point.

4.2.1 Problem Statement

When there is high traffic in the environment, or it gets very noisy due to other WiFi devices or other noise, it will become difficult for the WiFi client device to send keep-alive information to AP. If any packet does not deliver to AP via STA device in a particular time frame, AP will think that the device is not alive or switched to another AP. As a result, it breaks the established connection with that specific station. So, it is linked to failure cause of congestion [35].

4.2.2 Solution

The WiFi STA device will need to send keep-alive information to the Access point to establish a connection. Suppose there is high noise in the network and WiFi STA cannot deliver it to AP. In that case, the WiFi STA entity asks to transmit a packet with the help of BT radio to AP's BT entity, which notifies AP's connection maintainer that particular STA is alive. **Fig. 6** shows how a keep-alive packet is sent through BT/BLE interface. As discussed in architecture, both radios share the same shared memory. This keep-alive time maintained (Software or Hardware based) via WiFi entity can update via Bluetooth entity.

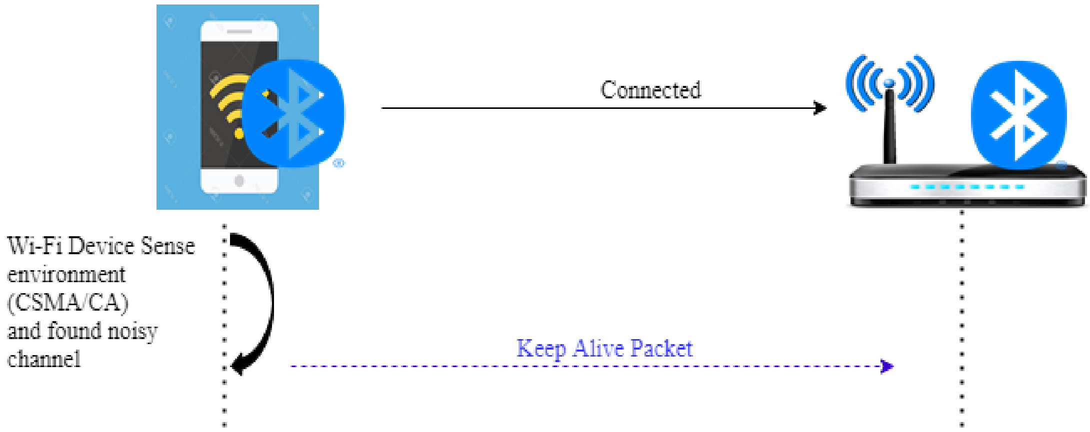

Fig. 6. Keep Alive Via BT Entity (In congested environment)

4.3 Keep link during power save mode

The connection must be alive with AP in this case, where the WiFi STA device is in power save mode. For a particular time when the device gets into sleep mode, there will be no transmission to AP.

4.3.1 Problem Statement

There is a particular interval for which AP expects to receive data, after which it imagines that the device is not alive anymore so that it may disconnect in this case. So, to keep this link, it is required that STA should transmit some active packets to AP at regular intervals. To send that keep-alive packet STA device needs to wake up for some time.

4.3.2 Solution

STA WiFi instructs to BT entity to continuously confirm activeness to AP, and then STA's BT entity will start transmitting data to AP. **Fig. 7** shows how a keep-alive packet is sent through BT/BLE interface when the WiFi device is in power save mode.

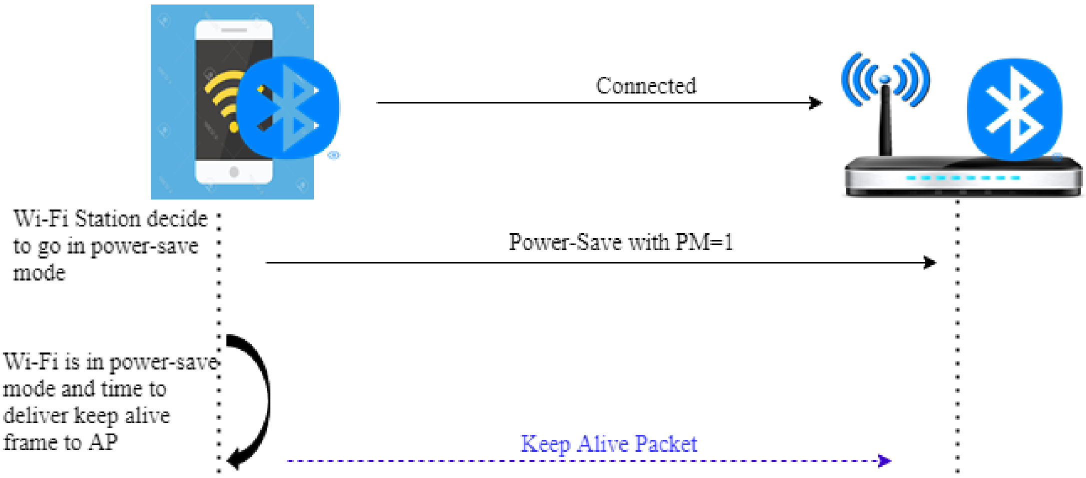

Fig. 7. Keep Alive Via BT Entity (In WiFi Power Save)

4.4 Aspects to conserve WiFi energy

In the present power save algorithms, the STA should awake in every DTIM Beacon to check the packet is present for the STA or not (**Fig. 8**).

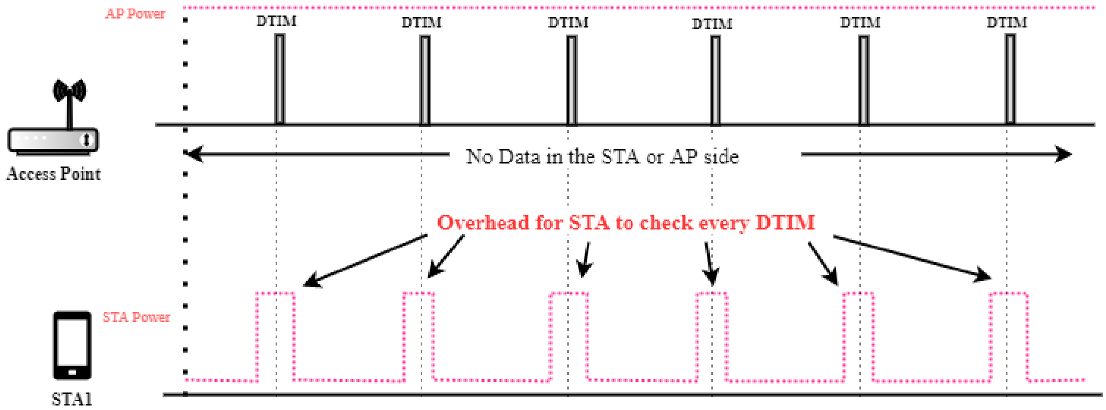

Fig. 8. WiFi Device Normal Wakeup Pattern

4.4.1 Problem Statement

If the packet is not present for the STA, it wastes much energy without any gain.

4.4.2 Solution

There are so many devices nowadays available which take less power to work. However, WiFi is the device amongst all others, which requires more energy. Bluetooth and ZigBee need less power as compared to WiFi. This technique will follow below mentioned concepts where STA will not be required to wake up on every DTIM beacon. BT/BLE, a less power-consuming technology, will play a crucial role here.

- Now on DTIM Beacon, there is no need for STA to wake up.
- If there are some packets on AP for STA, they will not be directly sent to STA. Instead, it will first trigger a command to the AP BT/BLE interface, waking up the STA.
- BT/BLE interface of AP will now send some selected packets to the STA BT/BLE interface.
- Then, the STA BT/BLE interface will decrypt the code and forward its respective signal to WiFi to wake up the WiFi module. It will save energy because WiFi will not be required to wake up every time.
- If needed WiFi to wake up, the WiFi segment will transmit a frame with the power save bit reset, and then its current power state can be indicated to AP.

Whenever AP has unicast data for the STA device, it will trigger a BT/BLE interface command to wake up the STA. After this, WiFi STA with Power management bit reset will send a wake-up notification to AP (**Fig. 9**).

Whenever there is a broadcast/multicast packets transmission, AP will not wait to wake STAs. It simply transmits a packet after the upcoming DTIM. AP will wake up STA immediately before the DTIM Beacon (**Fig. 10**). It will automatically save time, and obviously, it will consume less power.

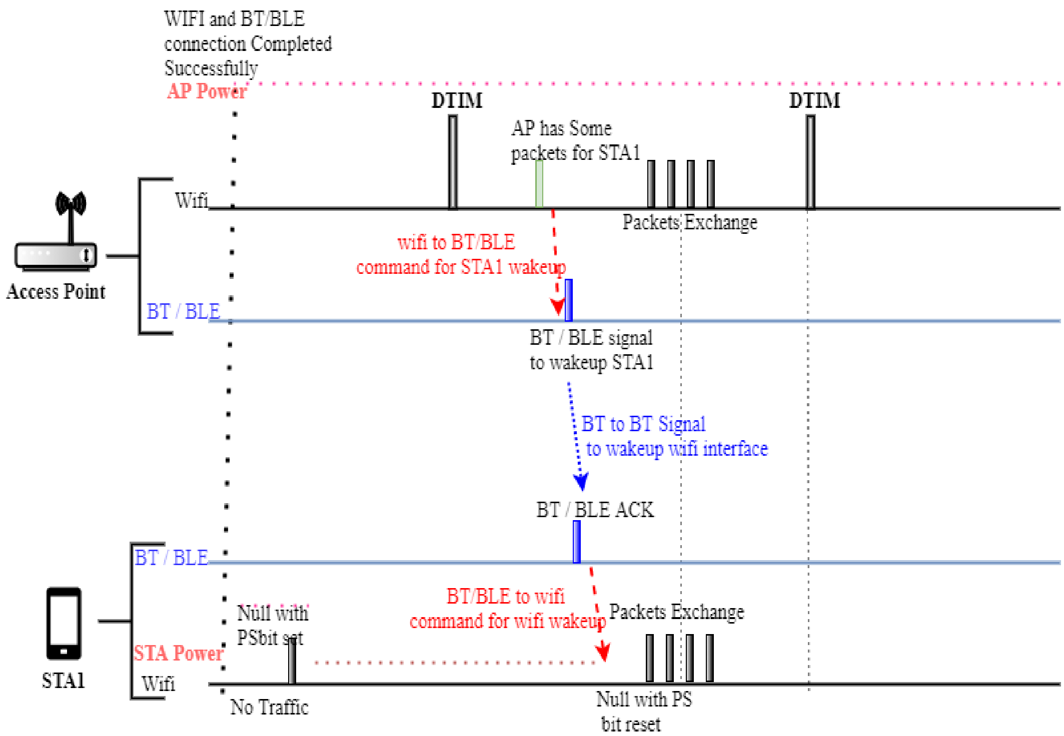

Fig. 9. Proposed Method in Case of Unicast Data Packet

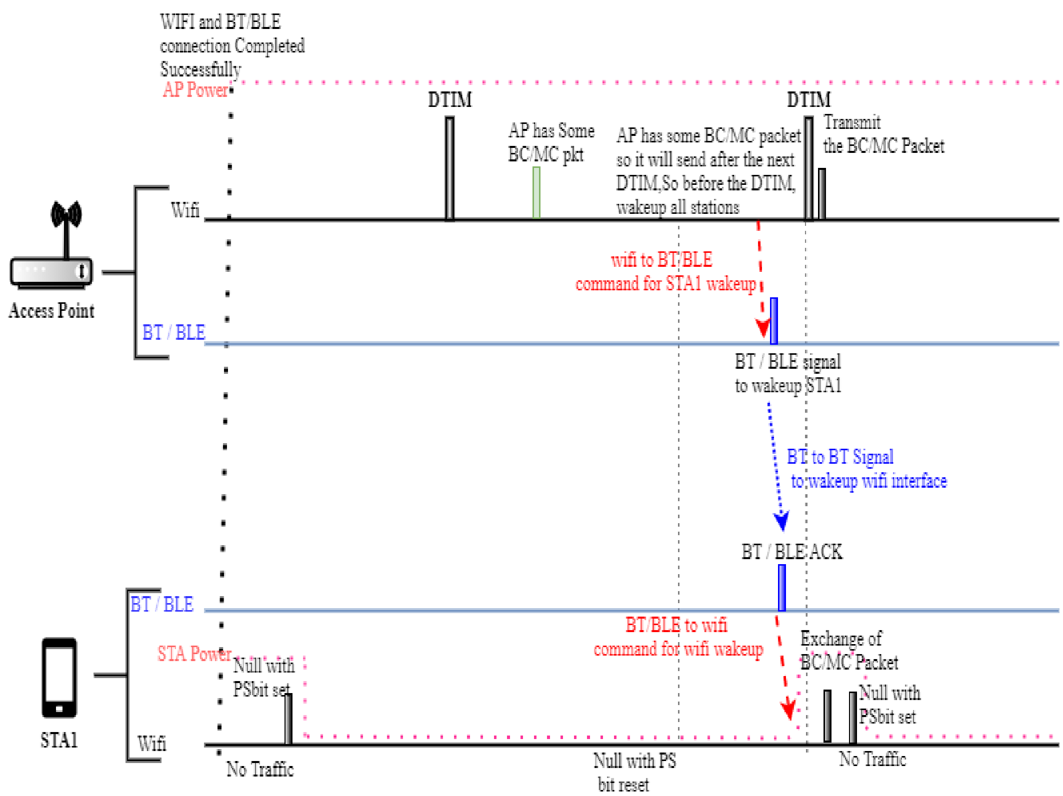

Fig. 10. Proposed Method in Case of Broadcast/Multicast Data Packet

4.5 Wake on Wireless LAN attributes: Partial energy conservation to complete energy conservation.

Wake on wireless LAN (WoW) is an operating system (OS) feature in which OS offloads the host side work to the firmware side. It means the Operating system; its processor can go into low power mode, but the WiFi device internal firmware/processor needs to be awake every time to handle some specific packet which the operating system asks to handle. The particular packet can be an ARP request, EAPOL packet, or another particular packet. So, this is a partial energy conservation method.

4.5.1 Problem Statement

The WiFi device's internal firmware/processor still needs to awake, and it is a waste of energy.

4.5.2 Solution

When Operating System enables the WoW feature at the Station side, it gives all the necessary information to its WiFi entity. The same information WiFi Entity can share with its Bluetooth/BLE entity, and WiFi can go into deep sleep mode; it means it can completely shut down its RF chain.

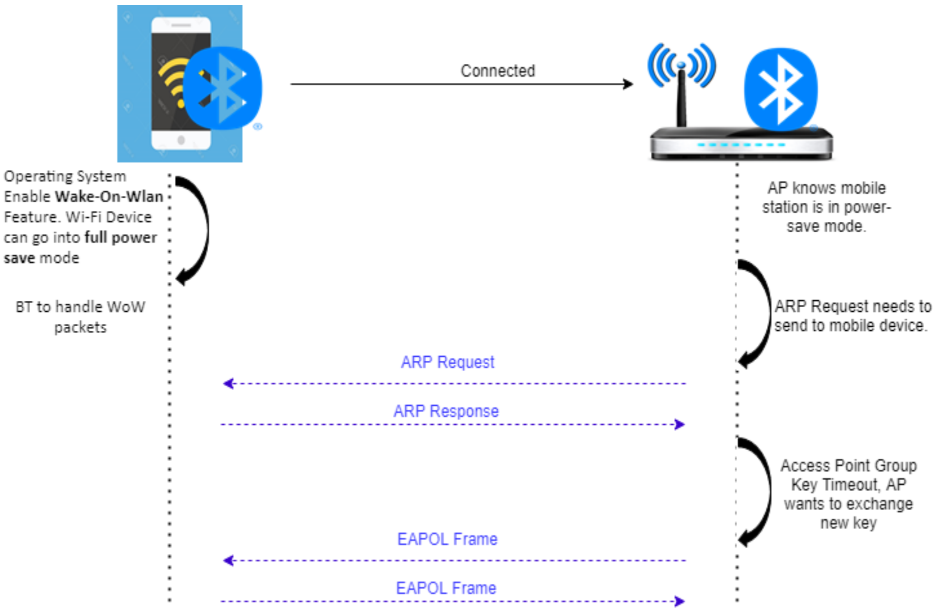

Fig. 11. Proposed Method in Case of Wake on Wireless Lan Scenario

AP should also know the situation before STA goes into full power save mode. So, when the operating system enables the WoW feature at the client-side, the client WiFi device needs to send a particular packet to AP (Vendor-specific action frame or data frame) so AP would know STA is in WoW mode. After receiving successful acknowledgment for this packet, STA can go into deep sleep mode. If any WoW-related packet comes, it can handle via Bluetooth Entity of AP and STA (Shown in **Fig. 11**).

5. Results & discussion

This part will evaluate the results in the standard scenario and our proposed model, synthesize the papers analyzed and provide advantages in other subsections.

5.1 Power consumption compare

When WiFi wakes up, sleeps, or receives any data, there will be some difference in power consumption. Again, switch on BLE in wake up, sleep mode, and receiving mode for various time intervals. Finally, we will be able to conclude which device must be kept and in which mode so that minimum consumption of power will take place and save more energy and money. We will calculate the power consumption of STA in legacy power save with light downlink traffic. The following acronym will use to calculate power consumption.

P_{idle}: power for an idle state
P_{sleep}: power for a sleep state
P_{wake}: power for an awake state
P_{sleep}: power for a sleep state
T_{DTIM}: beacon DTIM period
$T_{addition}$: extra time before the arrival of a beacon packet
S_{beacon}: size of a beacon frame
S_{SYN}: size of physical synchronization
S_{Header}: size of a MAC header
R_{PHY}: physical link data rate

$$P_{idle} = P_{sleep} + \frac{P_{wake} - P_{sleep}}{T_{DTIM}} * \left(T_{addition} + \frac{S_{beacon} + S_{SYN} + S_{Header}}{R_{PHY}}\right) \quad (1)$$

Here we take the Beacon frame as a reference frame and **Table 3** value taken for the calculation of P_{idle} [36].

Table 3. Default Values for the power calculation in the idle mode.

Parameter	Default Value
S_{beacon}	192 bytes
S_{SYN}	24 bytes
S_{Header}	34 bytes
R_{PHY}	1 Mbps
$T_{addition}$	2 ms
P_{sleep}	3.2 mW
P_{wake}	432 mW

In equation 1, put values from **Table 3**:

$$P_{idle} = 3.2 + \left(\frac{959.65}{T_{DTIM}}\right) \quad (2)$$

Energy took by the device to operate d days.

$$W_{idle} = P_{idle} * 24 * d \quad (3)$$

Power calculation in BLE [37]:
The average power consumed by BLE during advertisement/connection:

$$P_{bttx} = 1147.38uA * Vdd \quad (4)$$

The average power consumed by BLE in an idle connected state

$$P_{btidle} = 324.18\, uA * Vdd \quad (5)$$

Now BT will send keep-alive and check for Rx packet.
BT is taking approx T_{bttx} = 200us = 0.2ms for Tx as per reference [37].
The BT checks every TDTIM for the packet, then power consumed by BT:

$$P_{BTA} = \frac{P_{bttx} * T_{bttx} + P_{btidle} * T_{btidle}}{T_{bttx} + T_{btidle}} \quad (6)$$

Suppose BT is checking in every DTIM.

$$T_{DTIM} = T_{bttx} + T_{btidle} \quad (7)$$

And vdd=3V.

$$P_{BTA} = \frac{(0.68 + 0.972 * (T_{DTIM} - 0.2))}{T_{DTIM}} \quad (8)$$

Power calculation in Proposed Method:
BT will take care of the DTIM polling and keep-alive. So WiFi will act in sleep mode, and BT will operate in active mode.

$$P_{ourMode} = P_{btActivemode} + P_{wifiSleepMode} \quad (9)$$

$$P_{wifiSleepMode} = P_{sleep} = 3.2\, mw \quad (10)$$

$$P_{btActivemode} = P_{BTA} = \frac{0.68 + 0.972 * (T_{DTIM} - 0.2)}{T_{DTIM}} \quad (11)$$

$$W_{ourMode} = P_{ourMode} * 24 * d \quad (12)$$

The graph (**Fig. 12**) shows the power difference between standalone WiFi and Combined mode with different DTIM values for DTIM 50ms and 100ms (from equations 3 &11), the power difference is shown with the number of days between standalone WiFi and Combined mode (**Fig.s13 and 14**).

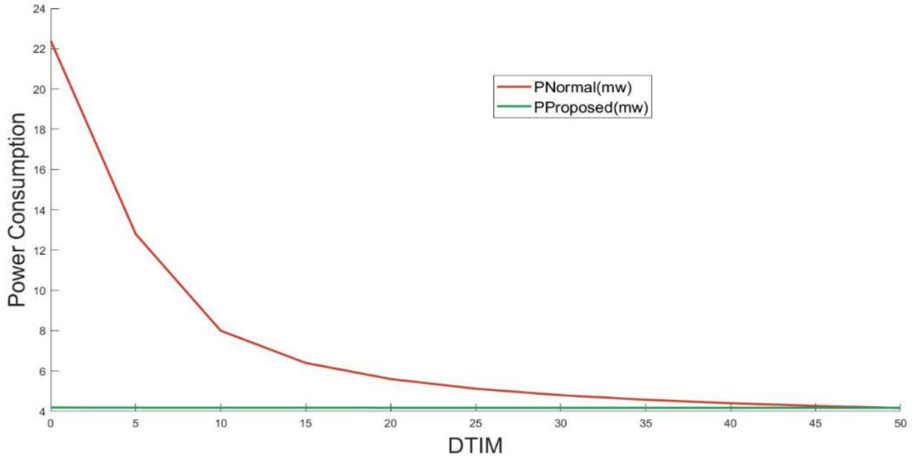

Fig. 12. Power graph between Normal scenario and the proposed method (equation 2 & 9).

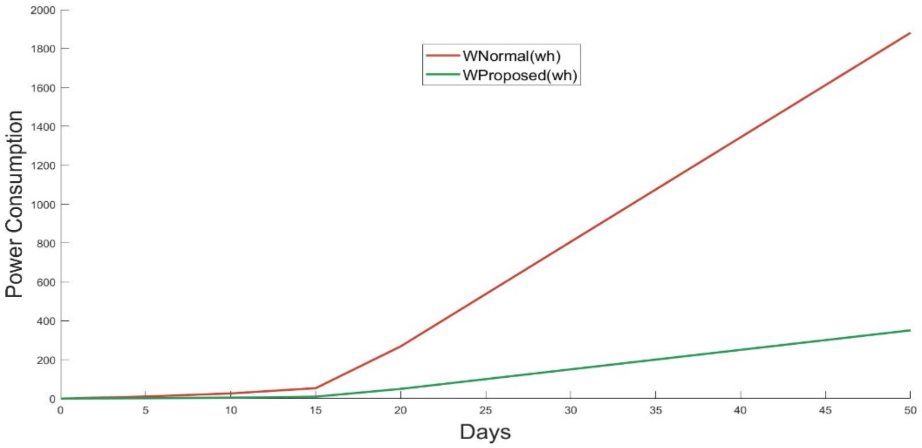

Fig. 13. consumption between normal scenario and with proposed method for DTM 50ms

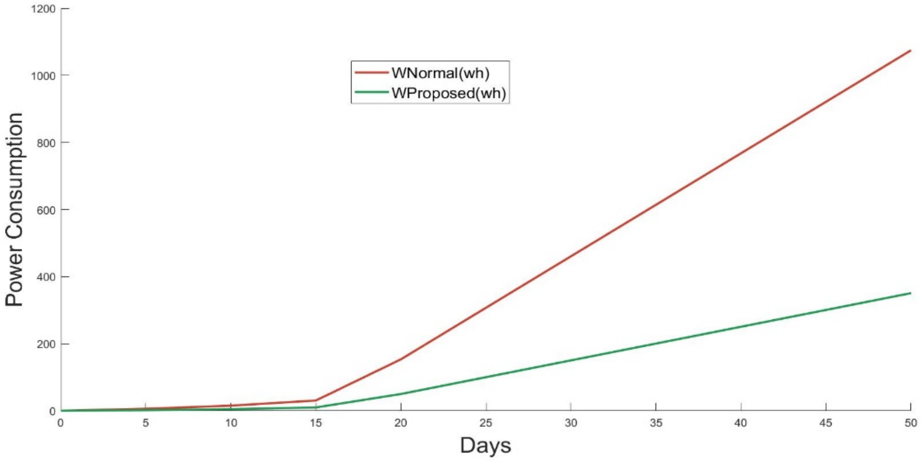

Fig. 14. consumption between normal scenario and with proposed method for DTM 100ms

5.2 Summary

Bluetooth is a critical short-range IoT communications Protocol. It has become very needful in computing. A new low-energy Bluetooth is now available, i.e., BLE, an essential protocol for IoT applications. BLE covers the same range as that of Bluetooth; in that same way, it also consumes significantly less power. As we have discussed, our proposed solution can provide the following advantages over standalone WiFi usage:

- A regular WiFi station device waking up will not occur on every DTIM, which helps with less energy consumption.
- Previously, there was a delay in transmission because of waiting for the STA device to wake up on DTIM; AP can wake up STA without delay.
- Other packets of WiFi that are connection-related can also be exchanged using this concept.
- Since the BT channel does not depend on the WiFi operating channel, the BT channel can use to communicate.
- The BT channel is used for reference here. Other less energy-consuming technology like Zigbee, NFC, UWB (Ultra-Wide Band) etc., can also be used.

- The proximity data provided by BLE is much more accurate than WiFi, so such a combination (WiFi with Bluetooth) can be advantageous in V2P (Vehicle to Pedestrian) and V2V (Vehicle to Vehicle). As suggested, instead of BT/BLE, UWB can also use in combination with WiFi. WiFi can be used for high throughput things like FOTA, and UWB can be used for positioning systems. UWB [38] uses a multi-sensor using TDOA (Time Difference of Arrival, time of arrival difference) and AOA (Angle of Arrival) positioning algorithm to analyze the accurate position with centimeters accuracy, highest safety and multi-path resolution. The possibility of getting disconnected will also be decreased in a high-volume 802.11 network.
- The 802.11 connection time will also decrease.
- As AP can wake up the STA device within a few seconds, there will be no need to buffer data DTIM, leading to shortening the buffer size of AP.
- Energy consumption will also decrease as 802.11 took much power, saved here.

6. Conclusions and future works

In this paper, we have discussed how low power technology can help to improve and maintain a WiFi connection and save power by considering some unique factors that remain unaddressed by the existing multi-radio mechanism. The paper specifically identified test cases in which low-power technology can help create fast connection, reduce power, and maintain the connection in a noisy environment. Mechanism and advantages discussed. We have provided a solution to improve the performance of 802.11 PSM using a combo solution. Our invention focuses on communicating the WiFi buffered packets (unicast/multicast/broadcast) status to STA using the active BT/BLE connection between BT/BLE peers present at the station & access point. The AP communicates buffered packet status to its corresponding active BT/BLE device, further communicating to STA's BT peer. The STA's BT peer will further notify its WiFi entity based on the received message. Based on the message, WiFi STA will take the appropriate decision to exit power save or not.

The proposed architecture shows how WiFi chip vendors can apply it in Mesh topology, how it will work, and whether a unique WiFi frame is needed. Finally, mathematical power consumption results show that the proposed mechanism can reduce power significantly, especially in the IoT devices era. The theoretical analysis and the experimental power results shown and the presented work are practical.

Although the suggested approach significantly improves the WiFi power-save & connection maintenance, it still has some points which must be taken care of in the future. The current approach should be tested under real environment, hence real-time implementation needs to be done by WiFi/BT chip vendors. WiFi packet (Management, Control, and Data) considered to identify valuable scenarios but Quality of Service (QoS) mechanisms also needs to consider for experimental setup [39]. Another limitation is with Bluetooth protocol. Bluetooth restricts the number of devices connecting to a single device because of the Logical transport address (LT_ADDR) of the Bluetooth baseband, which only has three bits. Our paper focuses on use-cases where Bluetooth can help, but the increased number of devices depends on chip vendors. Some proposals we can think about like:

- Divide STA devices into seven groups and the most significant bit of LT_ADDR can be used for the group, and another 2 bits of LT_ADDR can be used to point BT device under the group. So this way, four times BT device support can increase.

- Install a greater number of Bluetooth radios under the same SOC. With One WiFi radio, n number of Bluetooth radio can be present on the same hardware. Hardware is a one-time cost while it can permanently save lots of power.

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