IEEE 802.11bf WLAN Sensing Procedure: Enabling the Widespread Adoption of Wi-Fi Sensing

Tanguy Ropitault, Claudio R. C. M. da Silva, Steve Blandino, Anirudha Sahoo, Nada Golmie, Kangjin Yoon, Carlos Aldana, and Chunyu Hu

***Abstract*—In recent years, Wi-Fi has been shown to be a viable technology to enable a wide range of sensing applications such as device-free localization, motion recognition or human identification. Due to the growing interest in Wi-Fi sensing, Task Group IEEE 802.11bf (TGbf) was formed to develop an amendment to the IEEE 802.11 standard that will enhance its ability to support Wi-Fi sensing and applications. In this paper, we identify and describe the main definitions and features of the IEEE 802.11bf amendment as defined in its D0.5 draft. Our focus is on the Wireless Local Area Network (WLAN) sensing procedure, which supports bistatic and multistatic Wi-Fi sensing in license-exempt frequency bands below 7 GHz. We also present an overview of basic sensing principles, and provide a detailed discussion of features defined in the IEEE 802.11bf amendment that enhance client-based Wi-Fi sensing.**

I. Introduction

Wi-Fi sensing can be broadly defined as the use of Wi-Fi to acquire information on people, animals, objects, and/or locations of interest and enable applications such as user presence detection, environment monitoring in smart buildings, and remote wellness monitoring. While multiple sensing technologies are available, there are characteristics of wireless technologies that give *wireless sensing* and, in particular, *Wi-Fi sensing* certain distinct advantages. For example, compared to infrared-based sensing, wireless sensing works in non-line-of-sight conditions and supports wider coverage areas. As opposed to video-based sensing, wireless sensing can operate in poor visibility and lighting conditions and preserves user's privacy. Furthermore, in contrast to other wireless sensing technologies, Wi-Fi sensing leverages the fact that Wi-Fi is a relatively low-cost and widely deployed technology. Additionally, Wi-Fi is a standardized technology that allows for multi-vendor interoperability and supports data communications, ranging, and sensing with a single chipset.

The feasibility of using Wi-Fi to perform sensing has been evaluated and demonstrated in the past for applications as diverse as gesture recognition [1], people counting [2], and sleep detection [3]. The reader is referred to [4]-[6] for surveys of prior work in the area. Some commercial Wi-Fi sensing-based solutions are already available on the market and provide features such as residential security, elder care, and home automation [7], household motion detection [8], and presence location and posture recognition [9]. However, the range of applications currently supported is limited because the IEEE 802 standard does not currently define sensing-specific features, limiting Wi-Fi sensing to proprietary implementations with limited interoperability. For this reason, TGbf was formed in September 2020 to develop an amendment to the IEEE 802.11 standard that will enhance its ability to support Wi-Fi sensing[1].

The main contributions of the IEEE 802.11bf amendment are the definition of the *WLAN sensing procedure*, which supports sensing in license-exempt frequency bands below 7 GHz (2.4 GHz, 5 GHz, and 6 GHz), and its millimeter-wave (60 GHz) counterpart, the *Directional Multi-Gigabit (DMG) sensing procedure*. The definition of two distinct sensing procedures is necessary because Physical (PHY) and Medium Access Control (MAC) specifications for the two bands are noticeably different due to unique propagation characteristics. In particular, the usage of beamformed communication in the millimeter-wave band to overcome the high propagation loss needs to be accounted for by the sensing protocol. In this article, we identify and describe the main definitions and features of the IEEE 802.11bf amendment as defined in its D0.5 draft [10], *with a focus on the WLAN sensing procedure*. Readers interested about DMG sensing can refer to [11] and [12] for a brief description.

The remaining sections of this article are organized as follows: We discuss first sensing architectures and some of the challenges to consider for a Wi-Fi sensing protocol, before presenting IEEE 802.11bf sensing for bands below 7 GHz. We focus then on the features that enhance client-based sensing. The last section concludes this article.

II. Primer on sensing architectures and Wi-Fi sensing challenges

In this section, we discuss how Wi-Fi naturally supports the typical sensing architectures, practical considerations for

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[1]TGbf released a first draft of the specification under development for comment collection in April 2022, and it is expected to go for its first IEEE 802.11 Working Group Letter Ballot and IEEE Standards Association Letter Ballot in January 2023 and September 2023, respectively. The amendment is expected to be ratified by September 2024.

the development of a Wi-Fi sensing protocol, and some of the challenges that must be addressed from a research perspective.

A. Sensing architectures

Sensing systems can be categorized based on the number of devices used to obtain sensing measurements. The simplest sensing architecture, referred to as *monostatic*, involves one device, which acts both as the transmitter and the receiver performing measurements. When measurements are made by a single receiver using signals transmitted by a single transmitter, which is not co-located with the receiver, the architecture is said to be *bistatic*. Finally, a system with more than one transmitter or receiver is referred to as *multistatic*. These architectures are naturally supported by Wi-Fi systems:

- Monostatic requires only one station (STA)[2] and at least two antennas. This architecture does not need any communication or coordination between multiple STAs from a sensing point-of-view and therefore does not need to be specifically addressed by a Wi-Fi sensing standard as long as it respects IEEE 802.11 mandatory requirements (e.g., channel access).
- Bistatic requires a communication between two STAs. It can thus be achieved between an AP and a client (a client being typically connected to a single AP).
- Multistatic requires communication involving more than two STAs and can thus be achieved between an AP and multiple clients either by obtaining measurements using signals transmitted by multiple clients or by transmitting signals that are measured by multiple clients.

It is worth mentioning that the set of sensing applications that can be supported with measurements obtained by a client (bistatic) is limited compared to those that rely on measurements obtained by an AP, which is typically connected to multiple clients (multistatic). To address this issue, the IEEE 802.11bf amendment defines features specifically designed to enhance client-based sensing, as discussed later.

B. Practical considerations and challenges for sensing

1) Range resolution: Range resolution measures the ability of a system to resolve multiple targets in close proximity and can be written as $r_{res} = \frac{c}{2B}$, where c is the speed of light in vacuum and B is the sensing signal bandwidth. Fig. 1 shows the theoretical range resolution achieved with different wireless technologies and signal bandwidths. The range resolution of WLAN sensing is in the 0.5 m to 10 m range, and noticeably coarser than the resolution of other wireless technologies, including DMG sensing (60 GHz), due to the relatively narrow signal bandwidth used. Thus, at least in principle, WLAN sensing would be limited to low-resolution applications. However, the resolution achieved with WLAN sensing can be improved by exploiting Wi-Fi dense deployment. Specifically, it has been shown that WLAN sensing resolution can be noticeably improved in certain scenarios by intelligently combining low-resolution measurements obtained with multiple spatially diverse devices. For example, the performance of a motion detection and classification system was reported in [13] to have improved by 20 percent when two spatially diverse devices were used compared to a single device. A Wi-Fi sensing protocol must thus support bistatic and multistatic architecture to get a more accurate picture of the overall environment by combining one or more partial views obtained by spatially diverse devices. State-of-the-art data fusion techniques could be applied to combine efficiently the sensing measurements.

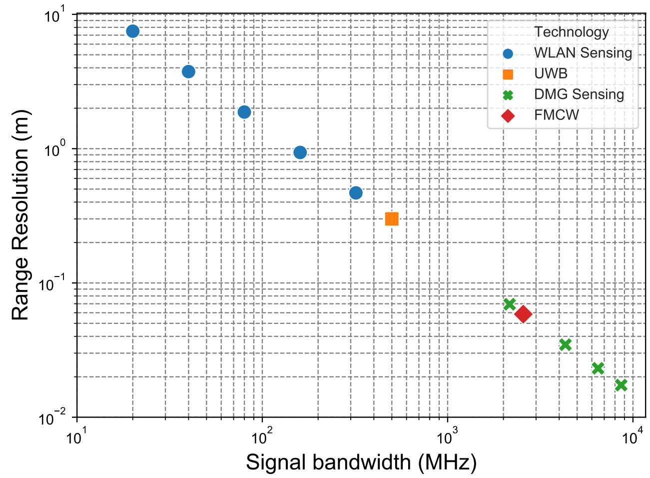

Fig. 1. Range resolution for different sensing technologies and signal bandwidths.

2) Sensing and interference: The accuracy of Wi-Fi sensing systems is dependent on the received signal-to-interference-plus-noise ratio of signals used for sensing measurements. Such behavior was quantified and analyzed in [14] by considering a set of Key Performance Indicator (KPI) metrics (e.g., range and velocity resolution) for Wi-Fi sensing-based home monitoring systems in a number of test cases and scenarios. While a Wi-Fi sensing protocol will benefit from the IEEE 802.11 channel access and collision avoidance mechanisms, it cannot avoid interference and as such, efficient signal processing algorithms (out-of-scope of IEEE 802.11bf) must be developed to accommodate low signal-to-noise ratio environment for sensing.

3) Joint sensing and communication: The primary objective of Wi-Fi is to transmit data. Sensing measurements can be seen solely as overhead for Wi-Fi systems, but at the same time, the sensing accuracy performance is strongly dependent on the availability and update frequency of sensing measurements. Thus, an efficient Wi-Fi sensing protocol should operate jointly with data transmission, and the allocation of sensing periods must minimize communication disruption while still preserving satisfactory sensing accuracy for a targeted sensing application.

4) Sensing measurements availability: Wireless sensing has transitioned from the usage of Received Signal Strength Indicator (RSSI) (readily available for any device) to Channel State Information (CSI) [4]. While CSI offers a detailed

[2] A STAs "is any MAC/PHY entity providing the IEEE 802.11 MAC services" [15], and includes both Access Points (APs) and non-AP STAs. Non-AP STAs are referred to as clients in this paper.

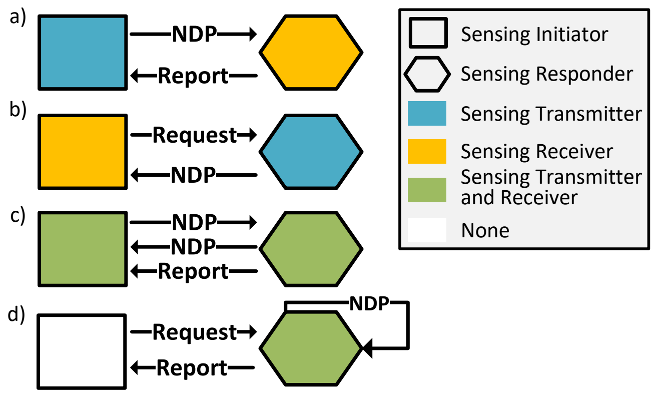

Fig. 2. WLAN sensing roles possible configurations.

representation of the channel compared to RSSI, it is not currently supported by the IEEE 802 standard. A Wi-Fi sensing protocol must guarantee the availability and the exchange of CSI between STAs to allow for interoperable sensing.

III. IEEE 802.11bf below 7 GHz

The procedure that allows a STA to perform sensing in frequency bands below 7 GHz is the *WLAN sensing procedure*. As depicted in Fig. 3, the WLAN sensing procedure is organized with *roles* and *phases*. The roles provide a sensing terminology to describe each STA role in the sensing framework, e.g., which STA initiates the sensing procedure, which STA performs measurements, etc. The phases organize the protocol operations that constitute the WLAN sensing procedure. The WLAN sensing procedure main goal is to enable STAs to:

1) inform other STAs of their sensing capabilities
2) request and setup transmissions that allow for sensing measurements to be performed
3) perform sensing measurements and exchange sensing measurement results
4) release resources allocated for sensing

A. Roles and configurations

A WLAN sensing procedure uses two sets of roles:

- *Sensing initiator* and *sensing responder*: to discriminate between the STA, called sensing initiator, that initiates the WLAN sensing procedure (i.e., the STA that supports a sensing application), and the STA, called sensing responder, that participates in the procedure by responding to the sensing initiator.
- *Sensing transmitter* and *sensing receiver*: to discriminate between a STA, called sensing transmitter, that transmits PPDUs to allow for sensing measurements and a STA, called sensing receiver, that receives PPDUs sent by the sensing transmitter to perform sensing measurement.

Fig. 2 summarizes the possible role combinations and associated message exchanges. The flexibility allowed by different possible role configurations aims at addressing with the use-cases envisioned for various sensing applications. We can first observe that the sensing measurements are obtained with

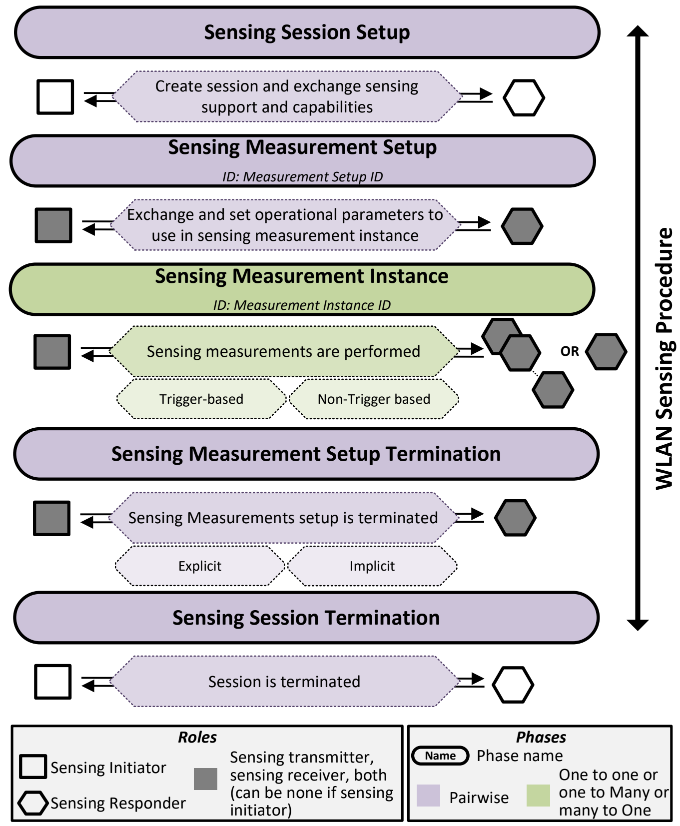

Fig. 3. WLAN sensing procedure overview

the transmission of *Null Data PPDUs (NDPs)*[3]. Then, the sensing report[4] can only be sent by a sensing responder acting as a sensing receiver or both sensing receiver and sensing transmitter.

The configuration depicted in Fig. 2.a uses an approach analogous to the approach employed by legacy IEEE 802.11 STAs to perform beamforming (the initiator sends NDP and the compressed beamforming beam steering matrix inferred from the channel response is reported), and as such, requires few modifications for vendor/implementors to support sensing. However, the downside of this approach is that first, a reporting phase is needed from the sensing responder(s) to the sensing initiator, generating additional overhead and additionally, the reporting phase may lead to information loss due to CSI encoding for measurement reporting. Fig. 2.b configuration is of interest, for example, when the sensing initiator wants to be the STA processing the sensing measurements, possibly taking advantage of proprietary algorithms. The main advantage of this architecture is that it does not require a reporting phase as the sensing initiator receives directly the NDPs and can thus perform sensing measurements. As a consequence, this architecture does not incur additional overhead nor produce any loss of information. The configuration presented in Fig. 2.c is

[3] An NDP is a packet that carries no data, and was originally specified to allow a STAs to perform channel sounding and compute beamforming steering matrices. Reusing the NDPs for sensing purposes allows to avoid any modifications to the PHY.

[4] CSI is the only measurement considered. Thus, it is also the only report.

beneficial when the channel reciprocity assumption (including RF front-ends) does not hold as it allows to obtain sensing measurements in both "directions". Finally, in Fig. 2.d, the sensing responder performs monostatic sensing. As discussed before, the IEEE 802.11bf amendment does not explicitly address this case for WLAN sensing.

B. Overview of the WLAN sensing procedure

As shown in Fig. 3, a sensing procedure is made of one or more of the following phases: Sensing session setup, sensing measurement setup, sensing measurement instance(s), sensing measurement setup termination, and sensing session termination.

Prior to any sensing measurements, the sensing initiator and sensing responder(s) must first determine their respective support for the WLAN sensing procedure and the sensing capabilities they implement if any. This is the role of the *sensing session setup*. The sensing session setup relies on procedures commonly used in the IEEE 802.11 standard, such as the association process.

Each sensing application has unique requirements in terms of sensing configuration and parameters, e.g., which devices perform sensing measurements, for how long, reporting parameters, etc. Thus, in the next phase, the sensing initiator must configure the sensing itself by exchanging and agreeing with each sensing responder on *Operational Parameters (OPs)* to use during the sensing. This is done by the *Sensing Measurement Setup*. OPs include , for example, the role of the sensing initiator and responder(s) (sensing transmitter, receiver, or both roles), or if sensing reporting is needed. A sensing measurement setup is initiated when the sensing initiator sends a Sensing Measurement Request Frame with the OPs to use with a sensing responder. The sensing responder must send a Sensing Measurement Setup Response frame in return that either accepts/rejects the request or proposes different OPs. In the Sensing Measurement Setup Request frame, the sensing initiator assigns a *Measurement Setup Identifier (MSID)* that, together with the sensing initiator's MAC address, is used to uniquely identify the OPs. A sensing initiator can configure sensing measurements to be performed by multiple responders using the same OPs (multistatic sensing). A sensing initiator can also establish multiple sensing setups with the same sensing responder to handle multiple sensing applications with different requirements.

Once the sensing measurement setup phase is completed, *sensing measurement instance(s)* occurs. Sensing measurement instances are packet exchanges between a sensing initiator and one or more sensing responders that allow for sensing measurements to be obtained. Sensing measurement instances are associated with a single set of OPs. The sensing measurement instance, being the essence of the WLAN sensing procedure, is described in detail in the next subsection.

When a sensing application no longer requires sensing measurements between a sensing initiator and a sensing responder, the *sensing measurement setup termination* is used. Two different variants exist: *explicit* and *implicit*. For the explicit sensing measurement setup termination, a STA (either the sensing initiator or the sensing responder) sends a Sensing Measurement Setup Termination frame (including the MSID) to the peer STA, terminating the measurement setup between these two STAs[5]. For the implicit variant, the sensing measurement setup is terminated at the expiration of the measurement setup expiry timer (set during the sensing measurement setup).

In the *sensing session termination*, STAs stop performing measurements and terminate the sensing session, releasing any resource associated to sensing (e.g., CSI report buffered).

C. Sensing measurement instance

Sensing measurements are performed during a sensing measurement instance. Each sensing measurement instance is assigned a *Measurement Instance Identifier*. Two variants of sensing measurement instances exist:

- *Trigger-Based (TB)*. In this variant, the sensing initiator is an AP, and one or more clients assume the role of sensing responders.
- *Non-TB*. In this variant, the sensing initiator is a client, and only one STA (an AP) assumes the role of sensing responder.

Both variants allow for measurements to be obtained in the *uplink* (AP is the sensing receiver), *downlink* (AP is the sensing transmitter), or both. However, the TB variant is the only one allowing multistatic sensing. Both variants allow for sensing measurements results to be reported if requested by using sensing measurement reports. CSI is the only sensing measurement defined by TGbf, and as such, is the only sensing measurement report available. [10] specifies that the CSI consists of the channel frequency response between each transmit antenna and each receive antenna used in the transmission and reception of the signal used for measurements. Using a procedure defined in [10], each raw channel frequency response is independently scaled and quantized before reporting. The scaling factors used in this process are included in the report so that sensing applications can scale received measurements back to their original values. To reduce the overhead of the report, sensing measurements are encoded into 8 or 10 bits, and only 1 out of 4, 8, or 16 subcarrier values are reported (in a process termed grouping in [15]) depending on the measurement configuration.

1) TB sensing measurement instance:

TB sensing measurement instance(s) between an AP and STA(s) take place during the period of time called the *sensing availability window*. A sensing availability window is made of one or more TXOPs (Transmission Opportunities)[6] and each TXOP consists of one or more TB sensing measurement instances. A TB sensing measurement instance may include the following phases:

- *Polling phase*
- *NDP Announcement (NDPA) sounding phase*
- *Trigger Frame (TF) sounding phase*
- *Reporting phase*

[5]Measurement setups with other STA(s) using the same MSID, if any, remain active.

[6]TXOP is the maximum time duration a station can send frames after gaining channel access.

During the *polling phase*, the sensing initiator determines the availability of sensing responder(s) at the start of the instance. The polling phase is typically required to overcome the fact that in the TB case, sensing responder(s) are non-AP STAs which might be in power saving mode even though they have accepted the corresponding sensing measurement setup. The NDPA sounding phase allows for measurements to be performed in the downlink; and the TF sounding phase, in the uplink. The *reporting phase* allows to feedback the measurement results obtained in the NDPA sounding phase. The presence of these phases is defined by the OPs set in the corresponding sensing measurement setup. For example, the reporting phase is only present when a sensing responder is a sensing receiver, and the OP defined in the sensing measurement setup states that the sensing responder must report obtained measurements.

An example of a TB sensing measurement instance in which channel measurements are obtained in both the downlink and the uplink is shown in Fig. 4. In the polling phase, the sensing initiator sends a *Sensing Polling TF* to the intended sensing responder(s). To indicate its availability, a sensing responder sends a CTS-to-self frame, Short Inter-Frame Space (SIFS)[7] after the Sensing Polling TF is received. CTS-to-self transmissions of multiple sensing responders are multiplexed using OFDMA. In the example given in Fig. 4, the sensing initiator sends a Sensing Polling TF to four sensing responders, but only three of them respond with a CTS-to-self frame. As a result, the fourth STA (STA 4) will not participate in the following phases. The TF/NDPA sounding phases are only present if:

- At least one sensing responder that is polled to serve in the role of sensing transmitter/sensing receiver responds,
- Or if at least one STA that is a sensing transmitter/receiver in this TF/NDPA sounding phase is not assigned to be polled[8]. In this case, the STA is always considered to be available in the subsequent TF/NDPA phases.

In the NDPA sounding phase, the sensing initiator is the sensing transmitter. To initiate the phase, an NDPA frame is sent providing the information necessary for the correct processing of the NDP, including intended recipient(s). After the NDPA is sent, a Sensing Initiator to Sensing Responder (SI2SR) NDP is transmitted within SIFS that allows for the downlink (Single-Input Single-Output (SISO) or Multiple-Input Multiple-Output (MIMO)) channel to be measured. In the example in Fig. 4, the NDPA frame and NDP are only sent to STA 3.

In the TF sounding phase, the sensing initiator is the sensing receiver, and transmissions from one or more sensing responders are solicited through the transmission of a TF. The TF allocates resources and establishes the timing of the Sensing Responder to Sensing Initiator (SR2SI) NDP that follows after SIFS. If more than one sensing responder transmits in this phase, their transmissions are multiplexed in the spatial domain using Multi-User MIMO. In the example in Fig. 4, both STA 1 and STA 2 transmit an SR2SI NDP.

[7] To gain access to the channel, a STA must defer for a fixed duration that is longer than SIFS. Thus, SIFS is used so that the sensing initiator and sensing responder maintain control of the channel during the frame exchange.

[8] The amendment draft defines the possibility for a STA to explicitly indicate that it does not participate to the polling phase, and yet will still participate in the sensing measurement instance.

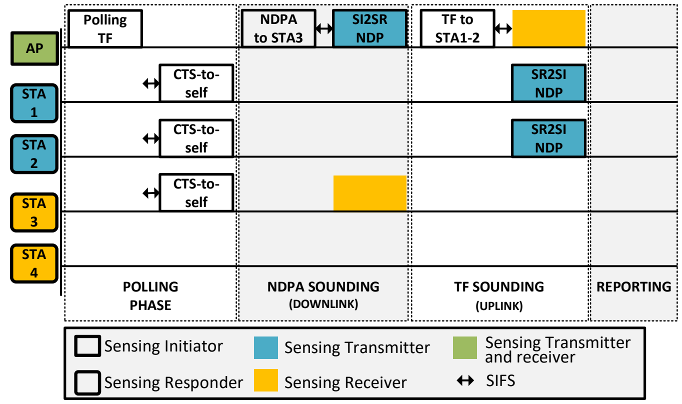

Fig. 4. Trigger-based sensing measurement instance. STA1 and STA2 have been assigned the sensing transmitter role in the sensing measurement setup phase while STA3 and STA4 are sensing receivers.

If enabled, the reporting phase provides the sensing measurement result of the sensing measurement instance(s). Two reporting phase variants exist: the *basic* reporting phase and the *threshold-based reporting* phase. The *basic* reporting phase is initiated when the sensing initiator sends a *Sensing Report TF*. The sensing responder sends a Sensing Measurement Report frame in response with either:

1) Measurements obtained from the SI2SR NDP of the current measurement instance (referred to as *immediate feedback reporting*)
2) Measurements obtained from the SI2SR NDP of the last measurement instance (*delayed feedback reporting*). In this case, a Sensing Measurement Report frame may contain measurements of different sensing measurement setups which reduces signaling overhead at the cost of increasing latency in the transmission of the reports.

The other TB reporting variant, the *threshold-based reporting*, is optional and reports the sensing measurements only if the reported CSI variation observed is greater than or equal to the CSI variation threshold value.

2) Non-TB sensing measurement instance: A client may initiate a non-TB sensing measurement instance whenever it gains channel access (without the need for a polling phase). Indeed, contrary to the TB case, the sensing responder in the non-TB case is an AP and thus never goes to power-saving mode. As illustrated in Fig. 5, a sensing initiator (STA1) initiates a non-TB sensing measurement instance by sending an NDPA frame to the sensing responder (AP), followed by an SI2SR NDP after SIFS. Once the SI2SR NDP is received, the sensing responder transmits an SR2SI NDP within SIFS to the sensing initiator.

Different from the TB variant, for ease of implementation, the packet exchange defined for non-TB sensing measurement instances is the same, as illustrated in Fig. 5, independent of whether measurements are obtained in the uplink only, downlink only, or both uplink and downlink.

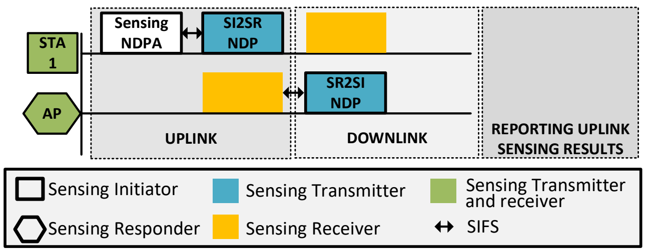

Fig. 5. Non-TB sensing measurement instance.

During the optional reporting phase, the AP sends a Sensing Measurement Report frame to the client SIFS after transmitting the SR2SI NDP.

Non-TB sensing is used when a sensing application is initiated by a client device and is limited to bistatic sensing. In the next section, we will see the features defined by TGbf defined to allow multistatic client-based sensing.

IV. Enhancing client-based sensing

Most Wi-Fi sensing systems currently found on the market use measurements obtained by APs and are thus multistatic. The development of client-based systems has been slower since they are typically bistatic, and as such providing limited resolution and support for various sensing applications. For this reason, IEEE 802.11bf has developed three features that enable a client to perform multistatic sensing.

A. Performing sensing as an unassociated STA

Before a client is allowed to exchange data with an AP, it must complete an *association process*. As defined in [15], association establishes a mapping between the AP and the client that allows for messages within the network to reach the AP with which the client is associated, and ultimately to the client. A client may only be associated with a single AP at a time, and therefore only exchanges packets with the AP with which it is associated.

There are usage scenarios, however, in which clients can receive packets from multiple APs, such as in commercial buildings with a managed 802.11 network. However, due to the association process, clients are not able to establish WLAN sensing procedures with more than one AP. This limitation also negatively impacts the IEEE 802.11 ranging procedure that allows for a client to determine its position by means of triangulation with multiple APs.

To address this limitation, Task Group IEEE 802.11az (next generation positioning) defined a procedure termed Pre-Association Security Negotiation (PASN) that allows for a client to exchange a limited set of frames with an AP without being associated with it. By using PASN, a client can perform ranging with multiple APs and determine its relative position.

IEEE 802.11bf has extended the set of frames that can be exchanged using PASN to enable clients to establish WLAN sensing procedures with APs (associated or non-associated). By doing so, clients can perform multistatic sensing in scenarios where multiple APs are found.

B. Sensing by proxy

While multiple APs may be available in places like commercial buildings, there are other places of interest, such as single dwelling homes, where this may not be the case. To address these cases, IEEE 802.11bf defined a procedure termed *Sensing by Proxy (SBP)* that enables a client to request an AP to establish WLAN sensing procedures with one or more clients and obtain sensing measurements on its behalf.

An SBP procedure starts with a client (*SBP initiator*) sending an *SBP Request frame* to an AP (*SBP responder*) that defines OPs to be used in the resultant WLAN sensing procedure(s). In response, the AP should send an *SBP Response frame* to the SBP initiator that either accepts/rejects the request or proposes different OPs. If the request is accepted, the AP initiates WLAN sensing procedure(s) with one or more clients (that may or may not include the SBP initiator) using the OPs requested by the SBP initiator. WLAN sensing procedures initiated as a result of an SBP request have the SBP responder as their sensing initiator, and follow the same protocol described earlier. Measurement reports can be sent by the AP to the SBP initiator.

C. Client-to-client sensing

In some scenarios, WLAN sensing performance could improve if clients obtained measurements using packets transmitted by other clients. For example, if clients in a given room (e.g., a smartphone and a computer) were allowed to perform sensing using packets transmitted by each other, an application may better "sense" the room (compared to the baseline case in which an AP, potentially in a different room is used). For this reason, a *client-to-client sensing* feature is defined in [10] (denoted by sensing responder-to-sensing responder) that enables a client to obtain sensing measurements using packets transmitted by other clients.

The client-to-client sensing feature does not enable a client to directly transfer data to another client, as the scope of the feature is limited to the transmission of packets used to obtain measurements (that is, NDPs). As a result, all phases of the procedure are controlled by an AP. To establish the procedure, for example, a client sends a request for client-to-client sensing to an AP, possibly identifying a requested list of client(s), and the AP, if it accepts the request, then exchanges frames with the intended clients to set up the procedure.

V. Conclusion and open challenges

Market interest in sensing technologies and, in particular, Wi-Fi sensing is significant and growing. The IEEE 802.11bf amendment will enable the widespread adoption of Wi-Fi sensing by defining specifications necessary to support a wide range of applications and configurations. Specifically, the amendment defines an interface for sensing applications to request and obtain sensing measurements, allow for sensing applications to use devices by multiple vendors, and lower the overhead associated with obtaining sensing measurements, among other features.

While TGbf has already laid solid foundations for an interoperable Wi-Fi sensing protocol, several open challenges still remain to be addressed. In particular, the overhead generated by the WLAN sensing procedure and its impact of Wi-Fi communication remains to be evaluated. Wi-Fi sensing is also a relatively new field and the development of a Wi-Fi sensing standard such as IEEE 802.11bf will unleash an increased demand for sensing applications, with requirements and use-cases non-envisioned during the definition of IEEE 802.11bf scope. A new Wi-Fi sensing amendment will be needed to iterate on top of IEEE 802.11bf to take into account these new requirements and usage.

The discussion presented in this paper provides a concise introduction to the IEEE 802.11bf amendment and to key PHY/MAC elements of Wi-Fi WLAN sensing. It is our hope that this paper promotes more interest and innovation within the area of Wi-Fi sensing.

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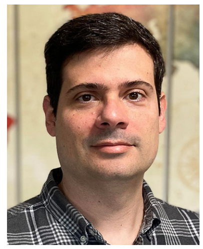

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