Impact of Beacon Interval on the Performance of WiFi-Based Passive Radar Against Human Targets

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***Abstract* — The capability of WiFi-based passive radar to detect, track and profile human targets in both indoor and outdoor environment has been widely demonstrated. This paper investigates the impact of the Beacon Interval (BI) on the passive radar performance. The results of a dedicated acquisition campaign show that both the detection capability and the localization accuracy progressively degrade as the BI increases due to both the reduction of the received beacons and to the intrinsic undersampling of the target motion. Limit values are suggested for practical applications.**

Keywords—WiFi transmissions; passive radar; human targets localization.

I. INTRODUCTION

In the recent years, great effort has been devoted to the localization of human targets in local area environments, thanks to the possibility to exploit positioning information for many applications, such as surveillance, monitoring, services, etc.

In the past, a few research groups developed WiFi-based passive radar [1]-[5], which performs the localization and tracking of moving targets. In particular, the localization can be performed using different set of measures, as for example range/Doppler/Angle of Arrival (AoA). The possibility to obtain the human target position without the necessity for the target to carry a device makes the WiFi-based passive radar attractive for local area surveillance and monitoring applications, especially where the targets cannot be assumed to be cooperative, as in typical security applications, as well in through the wall applications, [6]. As well known, the passive radar is very effective in detecting moving targets by using clutter cancellers. The extraction of stationary targets echoes is generally more complex and less effective. Moreover, due to the frequency bandwidth of the WiFi waveforms, spanning from 11 to 20 MHz, the range resolution is not better than a few meters, which makes it difficult to discriminate closely spaced persons. In contrast, good Doppler frequency resolution is available, which provides good localization performance when the target is well separated in Doppler from the other targets and even allows to obtain cross-range profiles, [7]. In this case, it is typical that a big number of echo packets can be integrated, so that a reasonable power can be collected from the target, which in turn provides an accurate position measurement. The number of pulses available depends on the Beacon Interval that is defined as the time spacing from consecutive beacons, which are packets periodically sent by the Access Point (AP). However, when the Beacon Interval (BI) decreases, the nice performance tend to degrade. In this work, we show the result of controlled localization experiments that allow us to analyze this degradation. An analysis of some important effects of this type was already provided in [8]. In this paper we analyze the impact of the longer BI not only on the target detection, but also on the accuracy of the measurements and finally on the 2D localization.

II. EXPERIMENTAL CAMPAIGN

The tests were performed in an outdoor environment (a parking area in Cisterna di Latina, Italy). A commercial wireless AP (D-Link DAP 1160), based on the IEEE 802.11 Standard, [9], was used as illuminator of opportunity, and connected to a transmitting directive antenna. The AP was configured to transmit in channel 4 of the WiFi band (carrier frequency equal to 2.427 GHz) and its BI was varied from 3 to 48 ms.

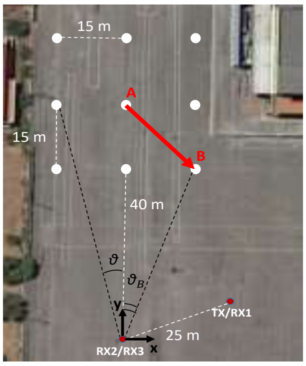


Fig. 1 - Target localization and tracking experiment

Three surveillance antennas (D-Link ANT24-1200) were used to collect the scattered signals. These antennas are characterized by a Horizontal Half Power Beam Width of about 80° and a peak gain of 12 dBi. As displayed in Fig. 1, two receiving antennas were located one beside the other, near the receiving system, whereas the third one was placed 25 m far from them, close to the transmitting antenna. The four-channel receiving system USRP 2955 by National Instruments was used to acquire the signals with a sampling frequency of 22 MHz.

During the acquisition measurements, we built a grid on the ground, whose 9 points have been used for the calibration stage and for comparing the estimated positions with the ground truth. For the calibration stage, we put the AP on each different point of the grid and we recorded few seconds of transmission. The AoA and the bistatic range have been evaluated for each point and then they have been compared with the ground truth. The Minimum Mean Square Error (MMSE) approach has been used to estimate the errors to be compensated for.

In this test, as shown in Fig. 1, a target moves from the central point of the grid, namely the point A in the figure, and arrives to the point B. Then he stops there for few seconds.

III. WIFI BASED PASSIVE RADAR PERFORMANCE

The passive radar processing scheme developed at Sapienza University of Rome ([3]-[4]) was applied. Fig. 2 shows the target detections in the bistatic Range-Doppler plane, for our case study. It is apparent that when the BI increases, the number of detections decreases and the non-ambiguous Doppler region is strongly reduced, as clearly displayed in Fig. 2(c)-(d). In particular, while for BI=3, 6 ms Fig. 2(a)-(b) shows many detections and a tracker is required to select the true target plots from false alarms and can be used to smooth their Doppler-range behavior, for BI=24, 48 ms many target plots are lost, so that the target tracking is required to fill the gaps and ensure continuity.

To obtain 2D localization, [4], in addition to bistatic range, the target AoA, $\hat{\theta}$, is estimated from the phase difference, $\widehat{\Delta\varphi}$, between the signals collected by RX2 and RX3, as

$$\hat{\theta} = arcsin\left(\frac{\lambda \cdot \widehat{\Delta\varphi}}{2\pi d}\right) \tag{1}$$

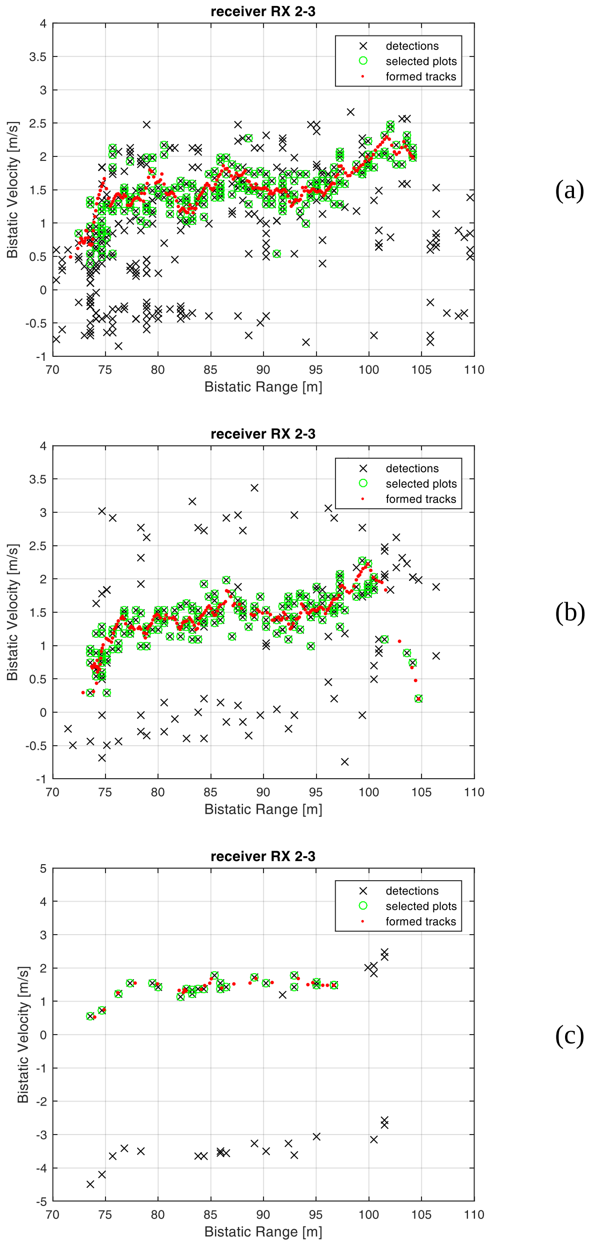
where λ is the wavelength related to the selected WiFi channel, and d is the distance between RX2 and RX3. To obtain a reliable estimate of the phase difference $\widehat{\Delta\varphi}$, a Maximum Likelihood estimation technique is used, which leads to expression:

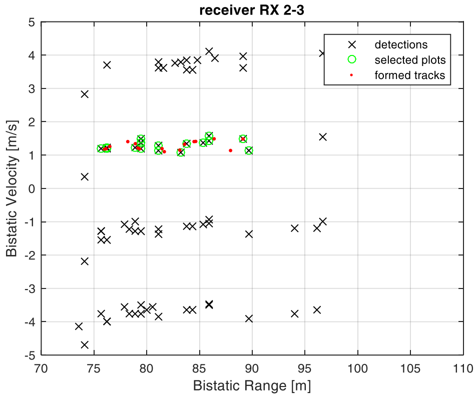
$$\widehat{\Delta\varphi} = \angle \boldsymbol{s}_2^H \boldsymbol{s}_3 \tag{2}$$

where $\boldsymbol{s}_2$ and $\boldsymbol{s}_3$ are the vectors containing the samples of the packets received from antenna RX2 and RX3, respectively.

The resulting AoA estimates (red dots), and their comparison with the ground truth (solid blue line), are shown in Fig. 3. In addition, the overall processed energy of the received signal is presented in the lower plot. Each point is the results of the coherent time integration of packets and depends on the number of beacon transmissions occurred in that particular time interval. Tracking is not used here, to better show the effect of the increase in PRI. In detail, with a BI of 3 ms (Fig. 3(a)) and an integration time equal to 0.5 s, it is possible to integrate about 167 packets, while when the BI reaches 48 ms (Fig. 3(d)), this number decreases to about 10. Even in this figure, the results show that the main problem of increasing the BI is the loss of detections, and accordingly, of the AoA estimates. Moreover, it is possible to notice that also the accuracy is affected by the integration of less beacons, due to the degradation of the Signal-to-Noise Ratio (SNR) of the employed signals.

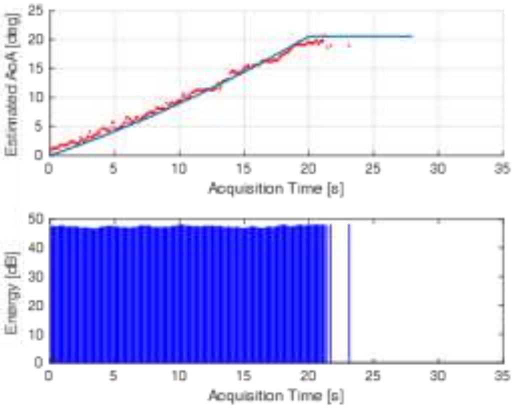
To understand better the accuracy, in Fig. 4 we show the AoA estimation error as a function of the time instant t_k, $e(t_k)=\hat{\theta}(t_k)-\theta(t_k)$, where $\hat{\theta}(t_k)$ is the estimated angle of arrival, whereas $\theta(t_k)$ represents the ground truth. It is apparent that the time slot where estimates are available is reduced, continuity is lost and in some cases (Fig. 4(c)) even some bias can appear.



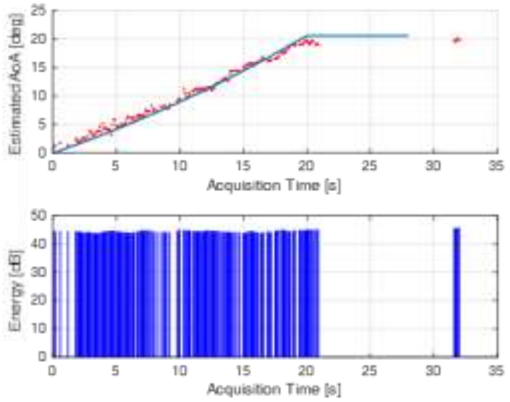


(d)

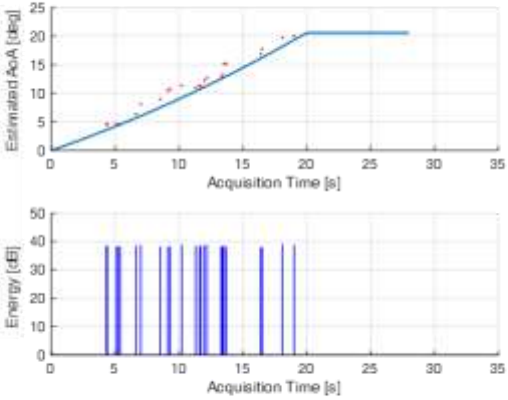
Fig. 2 - Target detection in the bistatic Doppler-Range plane for: (a) BI =3 ms, (b) BI = 6 ms, (c) BI = 24 ms, (d) BI = 48 ms.



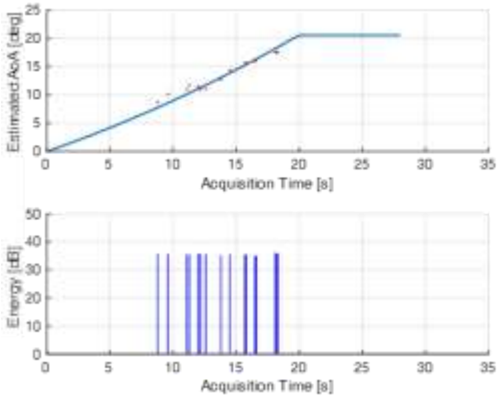
(a)



(b)

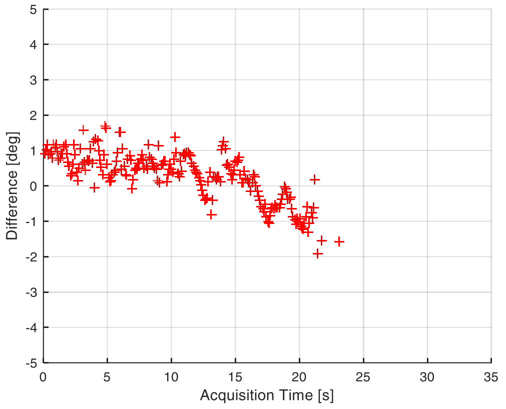


(c)



(d)

Fig. 3 - Target AoA vs time (upper plot) and Energy vs. time for: (a) BI =3 ms, (b) BI = 6 ms, (c) BI = 24 ms, (d) BI = 48 ms.



(a)

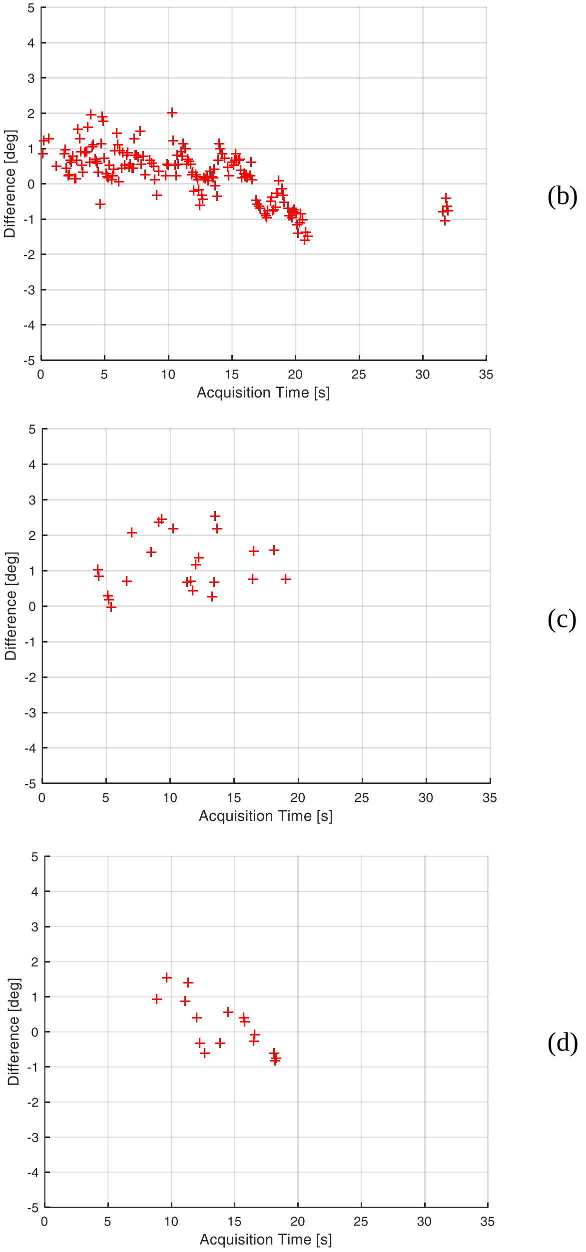


Fig. 4 - Target AoA error vs. time for : (a) BI =3 ms, (b) BI = 6 ms, (c) BI = 24 ms, (d) BI = 48 ms.

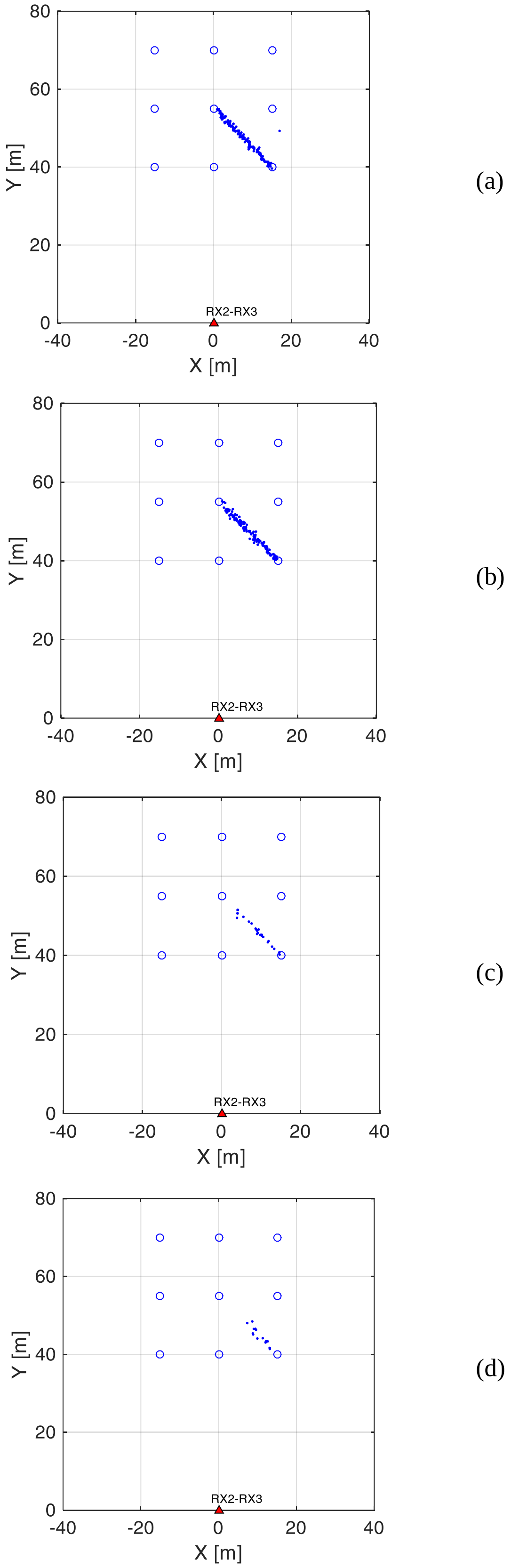


Fig. 5 - Target detection in the X-Y plane for: (a) BI =3 ms, (b) BI = 6 ms, (c) BI = 24 ms, (d) BI = 48 ms

By combining the two measures of AoA and bistatic range, the position estimation is easily obtained in the XY-plane, as shown in Fig. 5, where the blue circles indicate the nine points of the grid created on the ground. It can be noticed that the path of the target is correctly identified if compared to the theoretical behavior (see red line in Fig. 1), especially when a small BI is used. According to the previous considerations, it is evident that increasing the BI, some position estimates are missing. This behavior is negligible when we pass from 3 ms to 6 ms, but becomes relevant for higher values of BI. In particular, for BI = 48ms, we lose the entire first part of the target motion, so we cannot find continuously the target position.

IV. CONCLUSIONS

In this paper, we have investigated the impact of Beacon Interval on the performance of WiFi-based passive radar, which exploits the signals emitted by the AP. We have shown that the passive radar provides quite accurate measurements when the beacons emission is more continuous, namely when the BI is smaller. Its quality tends to degrade when the number of emitted beacon signals is strongly reduced, which might represent the situation where a significant activity is performed by other users of the medium. In particular, we have seen that the main problem when we use higher BIs is the loss of detections, which causes the impossibility to define the target position for the entire observation time and affects estimation accuracy. The results are largely in agreement with the study presented in [8], where the detection performance were addressed especially for vehicular targets. The better performance provided by the passive radar with BI equal to 3 ms or 6 ms is paid in terms of a higher computational cost with respect to the other investigated cases.

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