Paper Review 3

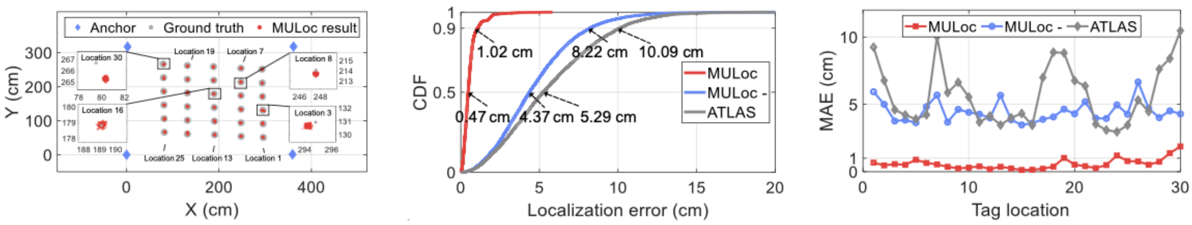
1. Paper summary.

   This paper addresses the challenge of achieving high-precision localization for a large number of devices using ultra-wideband (UWB) signals. Existing UWB systems can only provide centimeter-level accuracy and usually require tight synchronization between anchors, which increases complexity and limits scalability. Previous methods such as time-based (ToF/TDOA) and angle-based (AOA) approaches suffer from coarse timing resolution or limited antenna arrays, making millimeter-level accuracy difficult to achieve.

   To solve these issues, the authors propose MULoc, a new UWB localization system that introduces an Anchor Overhearing (AO) mechanism. In MULoc, anchors not only transmit but also listen to each other's signals, allowing the system to cancel hardware and clock errors through signal-difference-based processing. The method also combines fusion filtering and frequency hopping to resolve phase ambiguity and further improve precision.

   Results show that MULoc achieves a median localization error of 0.47 cm and a 90th-percentile error of 1.02 cm, improving accuracy by over 90% compared to traditional methods. Moreover, the model also performs well in trajectory tracking experiments, maintaining millimeter-level accuracy during movement. Overall, the work demonstrates a scalable, high resolution, and low cost solution for localization in IoT applications like VR and motion capture.

2. Analyze the result figure(s).



(a) Localization result (b) CDF of localization error (c) Localization error of each tag location

Fig. 11: Overall localization performance.

   Problem / Hypothesis:
   The goal of this experiment is to evaluate how accurately MULoc can locate UWB tags compared to previous systems. The authors aim to show that their proposed method, which combines anchor overhearing and phase-based localization, improves positioning precision.

   Methodology:
   Four anchors are placed at the corners of the indoor area, and a tag is positioned at 30 different locations. Three systems are tested: the baseline

ATLAS (traditional TDOA), MULoc- (only using ToF estimation), and the full MULoc system that includes UWB signal recovery and fine-grained tag localization. The localization error at each tag position is recorded and visualized.

Result:

- Fig.11(a) plots the visualized tag positions (red) and ground truth (black). The red points almost overlap with the true locations.
- Fig. 11(b) shows the Cumulative Distribution Function (CDF) of localization error, where the x-axis is error distance (cm) and the y-axis is cumulative probability. The red line (MULoc) rises steeply near zero, while the blue (MULoc–) and gray (ATLAS) lines are much flatter, showing larger errors.
- Fig. 11(c) displays the mean absolute error (MAE) at each of the 30 test points. The x-axis represents location index, and the y-axis represents error (cm). MULoc's bar heights stay low and consistent, while ATLAS and MULoc– fluctuate more.

Analysis:
Figure 11(a) visually confirms that MULoc achieves precise localization, and the lack of any directional bias means the error is evenly distributed. In Figure 11(b), the steeper CDF curve shows that most errors are concentrated within a very small range, proving the system's high precision. Figure 11(c) demonstrates that the geometric position of the tag has little effect on performance—the error variation among 30 points is small. Comparing (b) and (c), we can see that using ToF alone (MULoc–) only brings limited improvement, while the full MULoc model provides a major performance boost. Comparing (a) and (c), the few points with slightly higher errors appear near the **upper-left area** of the test space, suggesting that **minor residual effects remain there**. Overall, the figures support the authors' claim that MULoc significantly outperforms existing UWB localization systems without overstating.

3. Strengths and weaknesses of this paper.

   Strength:

   - This paper proposes a novel Anchor Overhearing (AO) mechanism that removes the need for anchor synchronization while enabling millimeter-level localization. This is an original and practical idea that lowers deployment cost and complexity compared to traditional UWB systems.
   - The authors provide comprehensive experimental validation on commercial DW1000 modules, showing that MULoc improves the

accuracy of localization significantly. The inclusion of both static and trajectory experiments is a convincing demonstration of its real-world feasibility.

Weakness:

- The experiments are conducted in a relatively simple four-anchor setup, where all anchors are placed at the corners of a rectangular area. While this configuration is ideal for minimizing geometric uncertainty, it does not fully represent more complex or irregular deployments. **Even under this optimal setup, the results show a slight directional bias**—errors are larger near the upper-left region—suggesting that the system's accuracy may depend on anchor geometry.

4. Recommendation
   Overall recommendation: Weak acceptance.

5. AI Tools
   Use AI tools to explain the confusing part and summarize the points in the paper, including the problems, challenges, approaches, and the result. Also, the AI tools are used to generate the draft of my response, which I had revised later.