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Review article

A Comparative Review of Communication Technologies for Asset Tracking in Healthcare Facilities

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Abstract: Efficient asset tracking in healthcare facilities is essential to reduce delays, prevent equipment loss, and optimize operational workflows. This study systematically reviews four widely used technologies: Radio Frequency Identification (RFID), Near Field Communication (NFC), Global Positioning System (GPS), and Bluetooth Low Energy (BLE), based on six criteria: cost, accuracy, range, energy efficiency, ease of deployment, and scalability. RFID and NFC offer high accuracy in short-range use cases, but RFID requires substantial infrastructure, while NFC is limited by its manual operation. GPS is highly effective for outdoor tracking, though it struggles indoors. BLE provides a strong balance across all criteria and supports long battery life, making it suitable for large-scale indoor tracking. The review incorporates real-world case studies and proposes hybrid IoT-based systems that combine these technologies to achieve comprehensive coverage. Future research should focus on seamless indoor-outdoor handoff, energy-efficient synchronization, and the use of machine learning for signal optimization.

Keywords: Radio frequency identification, near field communication, global positioning system, bluetooth low energy, asset tracking, healthcare.

1. Introduction

Healthcare facilities manage a wide variety of assets, both stationary (e.g., patient beds, diagnostic equipment, cabinets) and mobile (e.g., infusion pumps, wheelchairs, portable oxygen tanks). Efficient tracking of these assets is essential to reduce delays, prevent loss, and maintain high standards of patient care while optimizing operational resources. Technologies such as Radio Frequency Identification (RFID), Near Field Communication (NFC), Global Positioning System (GPS), and Bluetooth Low Energy (BLE) have been widely adopted to support real-time monitoring and asset management in healthcare settings [1], [2].

Each of these technologies offers different strengths depending on the environment: BLE is well-suited for indoor and short-range tracking; GPS provides robust support for outdoor and inter-building tracking; NFC and passive RFID offer very short-range, often manual or proximity-based asset identification. These distinctions make it necessary to assess technologies based on specific use-case scenarios rather than treating them interchangeably.

While these systems offer substantial benefits for inventory management and equipment availability [3], their adoption still faces challenges, including high deployment costs, varying accuracy, and interference with existing hospital infrastructure. Nurses and doctors reportedly spend a significant portion of their shifts locating essential equipment, up to 6–9% in some cases [4], [5]. Moreover, legacy solutions like proprietary RFID or Wi-Fi-based RTLS may require costly infrastructure and risk interference with sensitive medical devices [6].

This review evaluates asset-tracking technologies in healthcare based on key parameters such as accuracy, cost, range, energy efficiency, and ease of deployment. It aims to clarify how each technology aligns with specific tracking needs, helping guide better implementation strategies and identify opportunities for future improvement.

2. Methods

This study focuses on the comparative analysis of commonly used communication technologies for asset tracking in healthcare facilities: RFID, NFC, BLE, and GPS. These technologies were selected due to their documented use in hospital environments and their varying applicability depending on use-case scenarios. RFID and NFC are often used for proximity-based tracking, which makes them suitable for short-range identification tasks. BLE supports continuous monitoring within indoor healthcare settings while maintaining low energy consumption. GPS is most effective for outdoor or inter-building tracking due to its wide coverage capabilities.

Six evaluation criteria were used to assess their suitability: cost, accuracy, range, energy efficiency, ease of deployment, and scalability. These factors reflect common operational priorities in healthcare settings, such as minimizing costs, ensuring real-time accuracy, and integrating systems with minimal disruption.

The literature review employed a systematic search strategy targeting peer-reviewed articles published between 2010 and 2024. Databases used include IEEE Xplore, PubMed, and ScienceDirect. Articles were included if they met the following criteria:

- Focused on the implementation of asset tracking systems within healthcare facilities.
- Provided empirical or case-based data on technology performance.
- Involved at least one comparison among RFID, NFC, BLE, or GPS technologies.

Articles were excluded if they:

- Focused on asset tracking outside of healthcare environments (e.g., logistics, agriculture).
- Did not include sufficient technical or performance data for comparative evaluation.

To facilitate comparison, each technology was rated qualitatively across the six criteria using a relative scale: High, Medium, or Low. These ratings were derived from a synthesis of findings across the selected studies, reflecting how each technology performs in comparison to the others within the context of healthcare deployment.

3. Results and Discussion

3.1. Overview of Technologies

Various asset tracking technologies are utilized in healthcare settings, each offering unique advantages and limitations.

3.1.1. Radio Frequency Identification

RFID uses radio frequency to transmit data that can be used as unique identifiers. In healthcare, RFID is employed to track medical equipment, beds, and mobile assets in real time. It supports integration with hospital information systems (HIS) for improved workflow and asset utilization [7], [8], [9]. Passive RFID tags are inexpensive ($0.10–$0.50), but large-scale deployment requires a significant infrastructure investment. UHF RFID can extend read ranges up to 3 meters, although accuracy can be impacted by electromagnetic interference and physical obstructions. Active RFID tags enhance range (up to 100 meters) and accuracy but require battery replacements every 3–6 months, increasing operational costs. A real-world implementation in a European hospital demonstrated that RFID-enabled asset management improved staff productivity, asset utilization, and service quality [10].

3.1.2. Near Field Communication

NFC is a secure, low-cost, short-range (under 10 cm) communication technology ideal for personnel and small asset tracking in localized spaces. While it lacks automatic detection, its manual scan approach increases control and accuracy in secure zones [11], [12], [13]. NFC systems are easily deployable and energy-efficient. A case study using NFC tags for patient identification during the COVID-19 pandemic demonstrated high user acceptance (mean TAM score: 4/5) and effectiveness in reducing misidentification risks in critical care scenarios [11].

3.1.3. Global Positioning System

GPS provides high-range outdoor tracking via satellite signals and is especially suitable for mobile medical assets, such as ambulances or inter-facility transport units. Indoors, however, GPS accuracy degrades significantly, often exceeding 10 meters of error. Thus, GPS is often integrated with indoor-capable technologies like BLE or RFID for seamless tracking [6]. A study employing GPS for ambulance routing achieved 99.15% accuracy using a deep learning model, illustrating its potential to optimize emergency response times and route planning [14].

3.1.4. Bluetooth Low Energy

BLE is a low-energy, medium to short-range wireless technology, cost-efficient and often used for indoor navigation in healthcare. BLE beacons provide accurate localization for tracking equipment, patients, and staff, and easily integrated with smartphones [15], [16], [17], [18]. BLE offers a compelling balance between cost, accuracy, and energy efficiency. Its suitability for large-scale indoor tracking is enhanced by signal processing techniques such as Kalman filtering, which improve localization precision [19], [20]. BLE devices can operate up to 2–3 years on a single coin cell battery, substantially longer than active RFID [21]. Yoo et al. successfully tracked 400 medical instruments across emergency rooms and ICUs using BLE beacons [1]. BLE's energy efficiency is quantitatively superior to alternatives, typically achieving 2-3 years of operation on a single coin cell battery compared to 3-6 months for active RFID.

The comparison of these technologies is shown in Table 1.

Table 1. Comparison of RFID, NFC, GPS, and BLE.

Technology	Cost	Accuracy	Range	Energy Efficiency	Ease of Deployment	Scalability
RFID	Medium (Low tag cost, high setup cost)	High (affected by EMI)	Short to Medium (UHF: up to 3 m, Active: up to 100 m)	Passive: High, Active: Moderate (3–6 months)	Moderate (easy integration with HIS)	High
NFC	Low	High	Very Short (<10 cm)	Very High	Easy	Low (limited by manual operation and range)
GPS	Medium	Low (indoors, >10 m error), High (outdoors)	Long-range (global)	Low	Complex (indoor integration required)	High (especially for outdoor mobile assets)
BLE	Low	Medium to High (±1.5 m with filtering)	Medium (10–30 m indoors)	Very High (2–3 years on coin battery)	Easy	High

3.2. Discussion

Each technology offers strengths suited to specific healthcare asset tracking scenarios. RFID is highly scalable and accurate for short- to medium-range tracking, with strong deployment results in European hospitals [10]. NFC, while limited in range, offers high security and effectiveness in patient-centric applications, particularly under pandemic conditions [11]. BLE balances cost, accuracy, and energy efficiency, making it suitable for large-scale indoor tracking systems; filtering methods further improve its performance [19], [20]. GPS excels in mobile, outdoor tracking applications, such as real-time ambulance routing and vehicle management [14], though indoor limitations necessitate integration with other technologies.

Real-world implementations illustrate the feasibility of combining technologies. These hybrid approaches offer a practical path toward comprehensive, real-time hospital asset management systems. Despite the benefits, challenges remain. High setup costs (especially for RFID and GPS), integration complexity, and environmental interferences (e.g., EMI or physical obstacles) may affect performance. Staff training and change management are critical for system adoption. Nevertheless, BLE’s long battery life, affordability, and proven performance suggest it can serve as a core component in hybrid tracking frameworks, enhanced with filtering algorithms and complementary technologies.

4. Conclusions

In summary, no single tracking technology perfectly meets all hospital asset tracking needs. The optimal solution depends on specific factors such as hospital size, asset mobility, operational budget, and deployment environment. RFID is excellent for managing hospital inventory indoors, while GPS enables outdoor mobility tracking. NFC shines in highly secure, manual applications, such as patient identification.

A hybrid approach is strongly recommended for healthcare systems requiring both indoor and outdoor tracking. For example, combining BLE for internal equipment tracking with GPS for mobile assets (e.g., ambulances) provides robust, scalable, and energy-efficient coverage. RFID can complement these systems for detailed indoor monitoring where BLE is unsuitable due to interference or infrastructure limitations.

Future research should focus on developing seamless IoT-based hybrid systems that integrate BLE, GPS, and RFID via gateway nodes. These systems should aim to ensure continuous indoor-outdoor handoff, low-latency data synchronization, and minimal power consumption. Additionally, implementing machine learning models for signal filtering and prediction can further enhance system accuracy and reliability.

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References

[1] S. Yoo, S. Kim, E. Kim, E. Jung, K.-H. Lee, and H. Hwang, “Real-time location system-based asset tracking in the healthcare field: lessons learned from a feasibility study,” *BMC Med Inform Decis Mak*, vol. 18, no. 1, p. 80, Dec. 2018, doi: 10.1186/s12911-018-0656-0.

[2] L. C. K. Man, C. M. Na, and N. C. Kit, “IoT-Based Asset Management System for Healthcare-Related Industries,” *International Journal of Engineering Business Management*, vol. 7, Jan. 2015, doi: 10.5772/61821.

[3] T. D. McAllister, S. El-Tawab, and M. H. Heydari, “Localization of Health Center Assets Through an IoT Environment (LoCATE),” in *2017 Systems and Information Engineering Design Symposium (SIEDS)*, IEEE, Apr. 2017, pp. 132–137. doi: 10.1109/SIEDS.2017.7937703.

[4] K. Bagheri Lankarani, S. Ghahramani, M. Roozitalab, M. Zakeri, B. Honarvar, and H. Kasraei, “What do hospital doctors and nurses think wastes their time?,” *SAGE Open Med*, vol. 7, Jan. 2019, doi: 10.1177/2050312118813680.

[5] J. Pancham, R. Millham, and S. J. Fong, “Evaluation of Real Time Location System technologies in the health care sector,” in *2017 17th International Conference on Computational Science and Its Applications (ICCSA)*, IEEE, Jul. 2017, pp. 1–7. doi: 10.1109/ICCSA.2017.7999645.

[6] F. Ahmed, M. Phillips, S. Phillips, and K.-Y. Kim, “Comparative Study of Seamless Asset Location and Tracking Technologies,” *Procedia Manuf*, vol. 51, pp. 1138–1145, 2020, doi: 10.1016/j.promfg.2020.10.160.

[7] Y. Álvarez López, J. Franssen, G. Álvarez Narciandi, J. Pagnozzi, I. González-Pinto Arrillaga, and F. Las-Heras Andrés, “RFID Technology for Management and Tracking: e-Health Applications,” *Sensors*, vol. 18, no. 8, p. 2663, Aug. 2018, doi: 10.3390/s18082663.

[8] W. Yao, C.-H. Chu, and Z. Li, “The Adoption and Implementation of RFID Technologies in Healthcare: A Literature Review,” *J Med Syst*, vol. 36, no. 6, pp. 3507–3525, Dec. 2012, doi: 10.1007/s10916-011-9789-8.

[9] A. Oztekin, F. M. Pajouh, D. Delen, and L. K. Swim, “An RFID network design methodology for asset tracking in healthcare,” *Decis Support Syst*, vol. 49, no. 1, pp. 100–109, Apr. 2010, doi: 10.1016/j.dss.2010.01.007.

[10] L. Castro, E. Lefebvre, and L. A. Lefebvre, “Adding Intelligence to Mobile Asset Management in Hospitals: The True Value of RFID,” *J Med Syst*, vol. 37, no. 5, p. 9963, Oct. 2013, doi: 10.1007/s10916-013-9963-2.

[11] O. Ebere *et al.*, “NFC tag-based mHealth Patient Healthcare Tracking System,” in *2022 3rd International Conference on Next Generation Computing Applications (NextComp)*, IEEE, Oct. 2022, pp. 1–6. doi: 10.1109/NextComp55567.2022.9932185.

[12] K. Saraubon, P. Chinakul, and R. Chanpen, “Asset Management System using NFC and IoT Technologies,” in *Proceedings of the 2019 3rd International Conference on Software and e-Business*, New York, NY, USA: ACM, Dec. 2019, pp. 124–128. doi: 10.1145/3374549.3374558.

[13] N. Shetty and H. Ragab-Hassen, “NFC-based asset management for medical equipment,” in *2015 IEEE 11th International Conference on Wireless and Mobile Computing, Networking and Communications*

(WiMob), IEEE, Oct. 2015, pp. 246–251. doi: 10.1109/WiMOB.2015.7347968.

[14] C. Selvan, B. H. Anwar, S. Naveen, and S. T. Bhanu, “Ambulance route optimization in a mobile ambulance dispatch system using deep neural network (DNN),” *Sci Rep*, vol. 15, no. 1, p. 14232, Apr. 2025, doi: 10.1038/s41598-025-95048-0.

[15] Q. H. Nguyen, P. Johnson, T. T. Nguyen, and M. Randles, “A novel architecture using iBeacons for localization and tracking of people within healthcare environment,” in *2019 Global IoT Summit (GIoTS)*, IEEE, Jun. 2019, pp. 1–6. doi: 10.1109/GIOTS.2019.8766368.

[16] Z. Iqbal *et al.*, “Accurate real time localization tracking in a clinical environment using Bluetooth Low Energy and deep learning,” *PLoS One*, vol. 13, no. 10, p. e0205392, Oct. 2018, doi: 10.1371/journal.pone.0205392.

[17] G. Alfian, M. Syafrudin, M. F. Ijaz, M. A. Syaekhoni, N. L. Fitriyani, and J. Rhee, “A Personalized Healthcare Monitoring System for Diabetic Patients by Utilizing BLE-Based Sensors and Real-Time Data Processing,” *Sensors*, vol. 18, no. 7, p. 2183, Jul. 2018, doi: 10.3390/s18072183.

[18] I. Bisio, A. Sciarrone, and S. Zappatore, “Asset Tracking Solution with BLE and Smartphones: An Energy/Position Accuracy Trade-Off,” in *2015 IEEE Global Communications Conference (GLOBECOM)*, IEEE, Dec. 2015, pp. 1–6. doi: 10.1109/GLOCOM.2015.7417782.

[19] K. Suseenthiran *et al.*, “Indoor positioning utilizing bluetooth low energy (BLE) RSSI on LoRa system,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 23, no. 2, pp. 927–937, Aug. 2021, doi: 10.11591/ijeecs.v23.i2.pp927-937.

[20] P. Spachos and K. N. Plataniotis, “BLE Beacons for Indoor Positioning at an Interactive IoT-Based Smart Museum,” *IEEE Syst J*, vol. 14, no. 3, pp. 3483–3493, Sep. 2020, doi: 10.1109/JSYST.2020.2969088.

[21] L. Bai, F. Ciravegna, R. Bond, and M. Mulvenna, “A Low Cost Indoor Positioning System Using Bluetooth Low Energy,” *IEEE Access*, vol. 8, pp. 136858–136871, 2020, doi: 10.1109/ACCESS.2020.3012342.