Leveraging Bluetooth Low-Energy Technology to Improve Contact Tracing and Define Close Contacts in Healthcare Settings during the COVID-19 Pandemic

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Biomedical Research

Background

- COVID-19 rapidly evolved into a global pandemic
- Role of contact tracing with isolation and quarantine in epidemic control
- Need for automated contact tracing
- Close contact: 6 ft for a cumulative total of at least 15 min over 24hrs

We set out to assess the usability and performance characteristics of Bluetooth Low-Energy (BLE) wireless technology for indoor localization focusing on clinician-clinician direct/ indirect contacts

Advantages: small size, easy configuration, energy efficiency, privacy

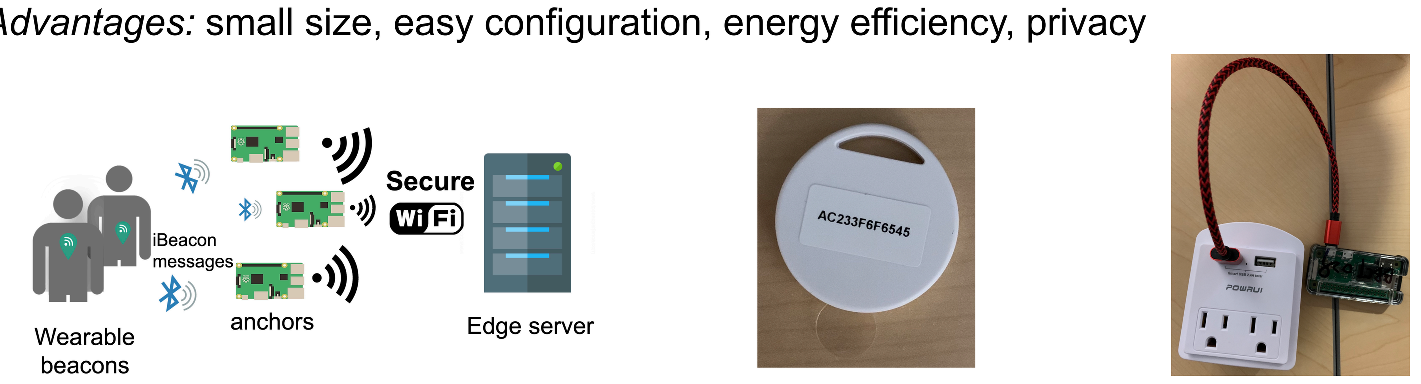


Fig. 1: System configuration. Healthcare workers (HCW) wear small signal - emitting devices called beacons. The signals are captured by embedded computers (anchors) placed at designated locations, characterized by received signal strength indication (RSSI), time stamped and transmitted via wifi to the edge server

Methods

- Phase 1: pre-clinical to test the optimal system configuration
- Phase 2: clinical to deploy and assess the accuracy of the BLE contact tracing on clinical COVID-19 wards. Consented HCW wore beacons for 6 months.

Recruitment: emails sent to all healthcare workers assigned to the 2 clinical study units

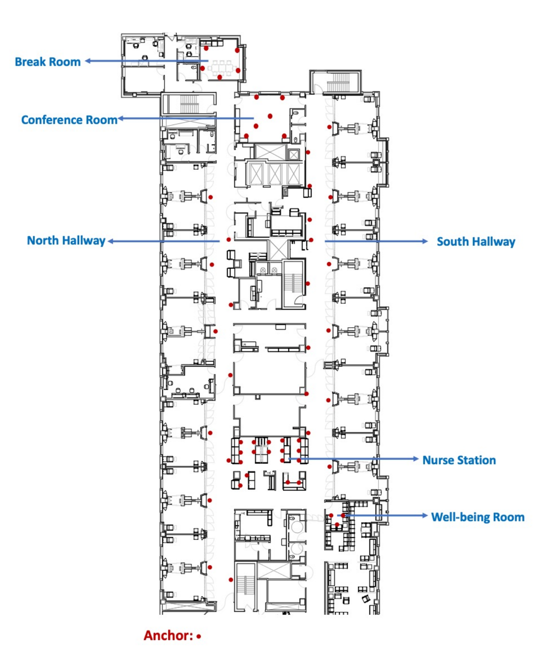


Fig. 2: Floorplan of the Intensive Care Unit part of the study showing the types of rooms and anchor placement.

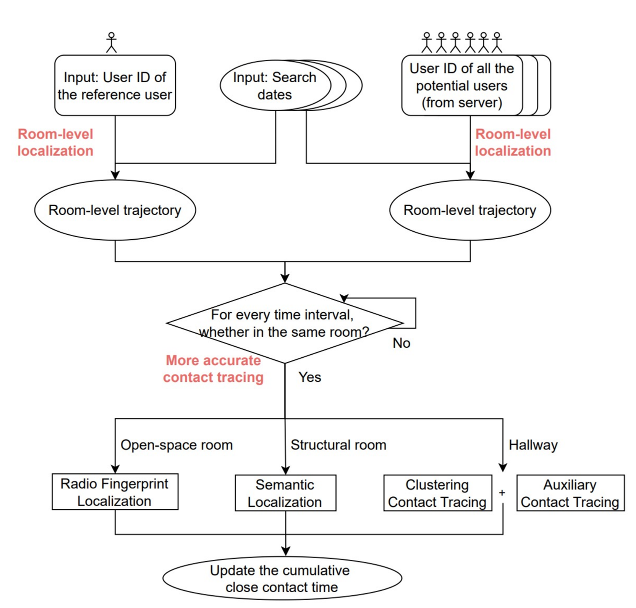


Fig. 4: General pipeline of the contact tracing system

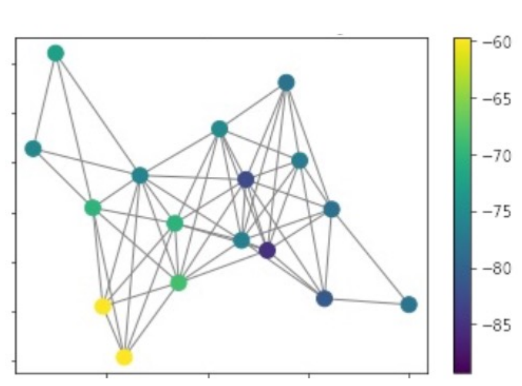


Fig. 3: Graph Signal in the Structural Room.
Each node is one anchor and the color represents the RSSI value at that anchor.

Experiments:
1) close contact per the CDC definition in the open space rooms (e.g. break rooms)
1) Semantic location in the structural rooms (nurses station) – graph-based fingerprinting
2) Dynamic clustering localization in the hallways using stationary and mobile computer anchors

Preprocessing:
1) Remove signal outliers outside of ± 1.5 IQR
2) Compute average value of RSSI per 10 sec for each anchor
3) Generate one RSSI vector for each time slot

Results

- Consent rate was 43.3% with 187 HCW enrolled in the study (86% in the ICU and among attendings, 0% for environmental cleaning).
- 100% compliance with wearing the beacons for the duration of the study.
- 98% accuracy in potential indirect transmission by correctly identifying used computer

	Duration (Minutes)	Accuracy before smoothness	Accuracy after smoothness
Trajectory 1	23.8	0.942	1.000
Trajectory 2	23.7	0.803	0.986
Trajectory 3	16.8	0.941	0.970

Fig. 4: Room level localization characteristics

Method	AUROC	AUPRC	Sensitivity	Specificity	Accuracy	F1 Score
Radio Fingerprint (NN)	0.8616	0.9388	0.6782	**0.9655**	0.7739	0.8000
Radio Fingerprint (WKNN)	**0.9326**	**0.9667**	0.8487	0.8851	**0.8608**	0.8905
Rank-based Fingerprint	0.6460	0.7849	0.6322	0.5326	0.5990	0.6776
Graph-based Fingerprint	0.9271	0.9613	**0.8985**	0.7663	0.8544	**0.8916**
Trilateration	0.6231	0.7878	0.7375	0.4061	0.6271	0.7250
RBO Similarity	0.8477	0.9323	0.6973	0.8391	0.7446	0.7845

Fig. 5: Break room level localization performance characteristics

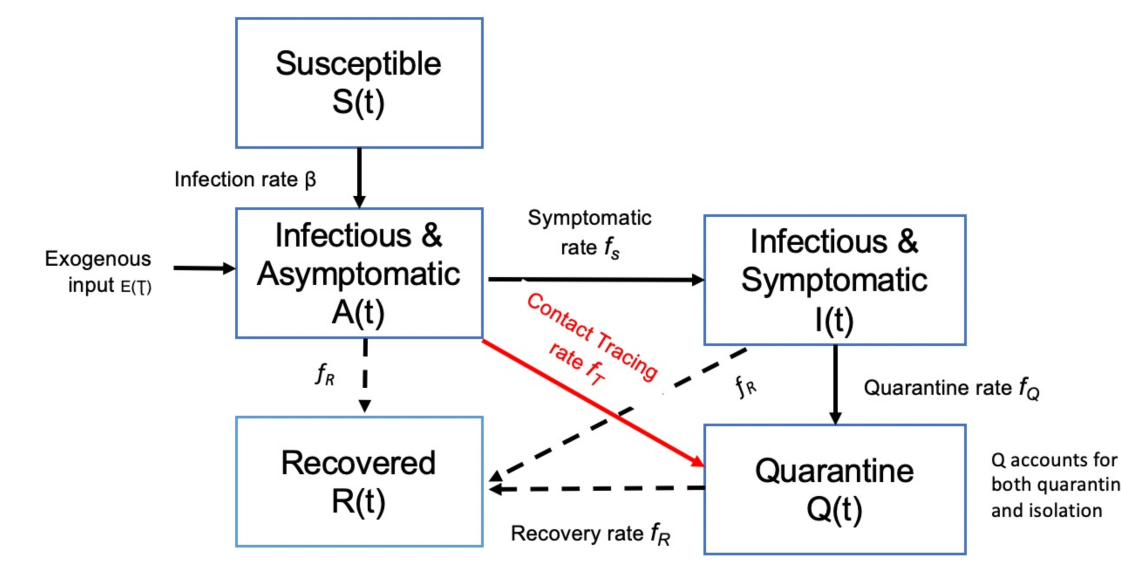
Method	Sensitivity	Specificity	Accuracy	F1 Score
Radio Fingerprint (NN)	0.6587	0.8334	0.6995	0.7707
Radio Fingerprint (WKNN)	0.6762	0.8293	0.7119	0.7826
Rank-based fingerprint	0.6536	0.8357	0.6961	0.7673
Graph-based fingerprint	0.6845	0.8325	0.7190	0.7888
Trilateration	0.7822	0.7774	0.7811	0.8456
RBO similarity	0.7656	**0.9062**	0.7984	0.8534
Clustering Contact Tracing (Ours)	**0.8648**	0.8921	**0.8711**	**0.9114**

Fig. 6: Hallway localization performance characteristics (including auxiliary methods)

Method	Localization Accuracy	Contact Tracing Sensitivity	Contact Tracing Specificity	Contact Tracing Accuracy	Contact Tracing F1 Score
Radio Fingerprint (NN)	0.8500	0.6591	**1.0000**	0.8636	0.7945
Radio Fingerprint (WKNN)	0.8114	**1.0000**	0.8712	0.9227	0.9119
Rank-based Fingerprint	0.4364	0.5000	0.7955	0.6773	0.5535
Graph-based Fingerprint	**0.9591**	**1.0000**	**1.0000**	**1.0000**	**1.0000**
Trilateration	0.6818	**1.0000**	0.7197	0.8318	0.8263
RBO Similarity	N/A	0.4545	0.5455	0.5091	0.4255
Max RSSI	0.8273	**1.0000**	**1.0000**	**1.0000**	**1.0000**

Fig. 7: Nurses' station localization performance characteristics

Susceptible, Exposed, Infected and Recovered (SEIR) model



Assumptions:
- constant daily SMALL exogenous input
- <1 day lag time for contact tracing
- Immediate isolation for symptomatic people

Goal: I <<< N and also Q <<<N

- average 20 contacts per 14 days –
- 5 distinct contacts per day
- role dependent

R_0=2.5

$R_{effective}$ decreased by 56% with BLE contact tracing
Overall false positive rate 86 HCW/day/10.000HCW

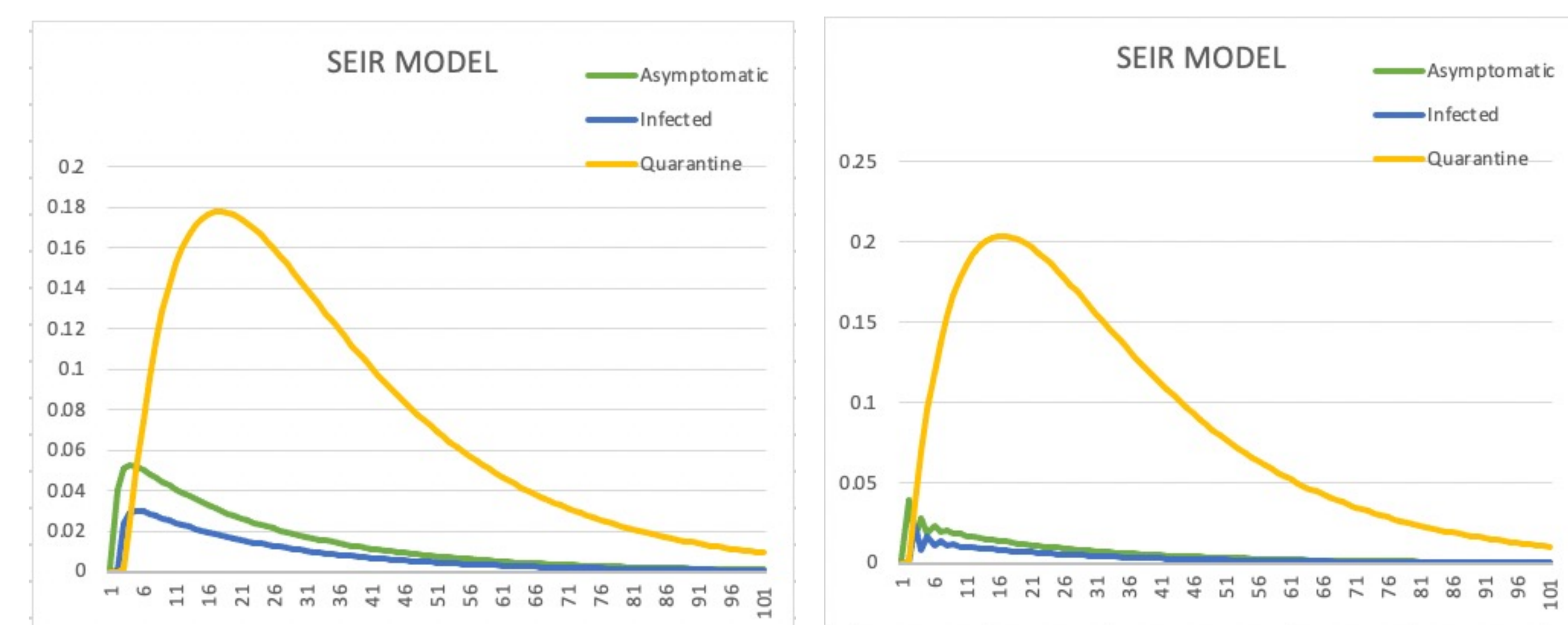


Fig.8: Panel A: Susceptible, Exposed, Infected, Recovered (SEIR) model in a hospital setting[1]
Panels B & C: Initiation of epidemic spread under baseline conditions (B) and BLE contact tracing (C)

Conclusion

We have developed and tested a reliable and accurate, low-cost and easily deployable system based on BLE technology to improve contact tracing among healthcare workers.

References:

Brown RA. A simple model for control of COVID-19 infections on an urban campus. Proc Natl Acad Sci U S A. 2021 Sep 7;118(36):e2105292118. doi: 10.1073/pnas.2105292118. PMID: 34475214; PMCID: PMC8433581

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