Ad-hoc wireless sensor communications for health monitoring systems

Prof. Dr. Mimoza DURRESI
mimoza.durresi@uet.edu.al

Abstract

The Covid 19 challenge, the increased aging population, and the modern way of living are increasing the need for health monitoring communications services. Healthcare monitoring is a very important research field of study. This is related in finding new, more efficient ways in health data communications with three main quality of service requirements: low delay, high security, high quality data transmission. Considering these requirements and recent developments in domestical health monitoring services, it is important not only the equipment used for health monitoring sensing but also the communication protocol used to access the data center. In this paper we develop a new communication protocol for ad-hoc wireless network created by the sensors used for personal health monitoring systems installed in patient wrists. This is a hierarchical protocol where the sensors communicate through a virtual infrastructure that helps to collect the data from the personal health monitoring equipments in an efficient way even in the areas with no wireless infrastructure. The communication scheme ensures a hierarchy of nodes that gets translated to hierarchy of costs as only a few nodes need to have a larger processing power resulting in a lower battery consumption for most of the patients. The neighbourhood area is divided into virtual cells where each cell is represented from one node center that holds the communication for all the surrounded nodes and forwards its information towards the next cell center found in the direction of the sink. As a result the information collected even in the fields without any wireless infrastructure might be carried towards the cells that are in a communication distance with the sink. The updated information data is forwarded toward the data centers to be analysed by the specialists. Taking in consideration that even in the urban areas the elderly population doesn't have internet services, this ad-hoc communication protocol represents a good solution for health monitoring *equipments. Moreover the same communication protocol can be used for signaling life signs in war areas.*

Keywords; *Wireless sensors networks, virtual infrastructure, wireless sensors protocols, health monitoring equipments*

Introduction

Social development, modern way of living and aging world population are causing larger percentage of world population living alone.

On the other hand, the Covid 19 pandemics and other public health threats, caused by natural or human disasters, are major concerns encouraging the development of new technologies for individual health monitoring systems that can optimize operation of the large scale health monitoring systems, notifying the health services when necessary.

The purpose of this paper is to contribute toward improving the use of individual health monitoring equipment in large scale population even in the absence of fixed or wireless infrastructure.

In this paper we study and design of a new ad hoc communication protocol that makes possible to have individual health monitoring equipment sense the need for emergency assistance by comparing the life sign data with the threshold registered ones and communicate with health services even in rural or under war areas.

Previous research

Many studies have been developed especially the past two years regarding the possibility of individual health monitoring equipment as a part of Internet of Things applications that can monitor and save lives. By analyzing most of the research work published on this direction, we conclude that there are two main issues: the communication protocol and the individual sensing equipment. The system needs to ensure an efficient communication protocol for having the quickest possible notification of critical health conditions toward the nearest health services. Also, it is important to develop a low-cost wearable equipment that would sense the vital parameters as pulse, oxygen levels, blood pressure etc.

The patient monitoring system involves the integration of many individual health equipment distributed over a large geographical area that would serve as nodes of an ad-hoc network, capable to communicate with each other according to a specific communication protocol. This communication protocol need to fulfill the following requirements: long communication distance between the critical health condition patient and the local health services or the Health Data Center, good communication quality even in rural areas; high integration range of wireless sensors as part of individual health equipment distributed over a large geographical area; immune to radio interference; the same technology distributed and implemented by many local municipalities; ensuring continuous health monitoring service for all the patients in the integration areas; practical wearable equipment and low-power consumption for ensuring long life battery usage, providing a good ratio cost performance solution.

The challenges are great considering the small communication distance capability of the health monitoring equipment due to the limited access resources of sensors like processing capabilities, available data storage or limited power sources.

Optimizing health monitoring services has always been of great the interest from research communities all over world, especially in the past two years. As we mentioned before there exists a lot of work previously done in the field of health monitoring of patients not hospitalized. In the research work presented from the collaboration of Shanghai Universities (Zhang et al.,2021) present a device for COVID-19 prevention that monitors and records continuously the important health data of a patient. According to their solution the equipment installed in patient wrist records two main parameters: the patient's body movements and the patient's body temperature, the data collected are transmitted to a computer using Bluetooth, the main problem with this solution is the short range of communication, about 10m. This solution is to be used in urban areas where the wireless infrastructure will support the data transmission from the PC to the local Health Services,

Another work to be mentioned is the research done from the collaboration of Islamabad, Pakistan-Aerospace University and South Korea (Ullah et al., 2021). According to their solution they propose a patient quarantine monitoring system using multiple sensors distributed over patient's body that will measure temperature, respiratory, accelerometer, pulse, SpO2 and the patient's location data given by GPS (global positioning system). As in the previous work the data are transmitted by using the Bluetooth towards the microcontroller and then toward the local server by using the Internet connection.

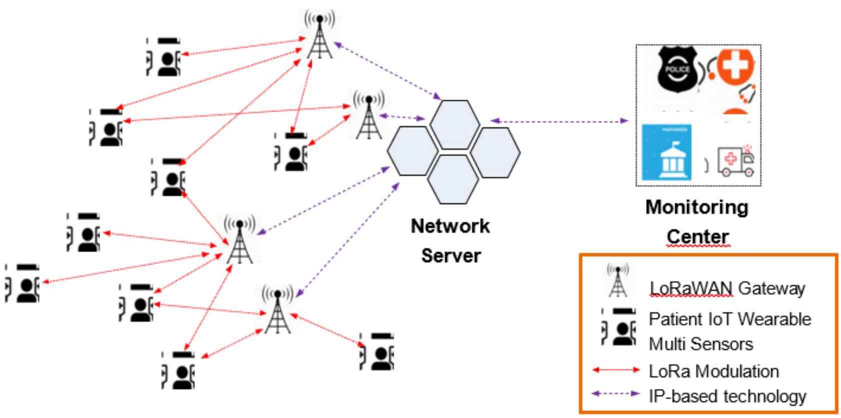
The system monitors the patient's health and his location to notify the services in the case that the patient would break the quarantine rules. As in the previous work mentioned the system works only in the presence of the Internet which means it doesn't support the use in the absence of the wired or wireless infrastructure, The other disadvantage is the complexity of the system as the sensors are distributed over patients' body which means that will be very uncomfortable and prone to technical defects.

Another solution is proposed by research developed at (Mukhtar et al.,2021) which is very similar to the abovementioned one and has the same disadvantage of using sensors distributed over patient's body and not a practical equipment. Regarding to data communication their solution is based to the use e of the wireless infrastructure as the data collected are sent and processed to the Cloud even though they use the IEEE 802.11 protocol only at the first hop.

Another work to be mentioned is the one from Salerno University presented in (Hoang at al., 2021) where they propose the use of a similar patient monitoring system. They use an accelerometer for recording the patient's movements and two temperature sensors (a contact one and an IR—infrared sensor) for recording the patients temperature. In addition, their solution includes two sensors to monitor the ambient condition such as temperature and humidity which are positive additions especially in the case of patients living alone. The data collected are transmitted toward a web-based application by using the Bluetooth which means that the system can't be used in the absence of the internet connection.

The group of researchers from University of Sucieva, Rumenia, (Lavric, at al., 2022) developed the system showed in Fig.1. Their Health Monitoring System uses LoRaWan, which means that their solution provides a better solution regarding the absence of the infrastructure, but still only in the first hop.

FIG 1: LoRaWAN multi-sensor patient monitoring architecture.



As mentioned before there are two challenges for Health Monitoring Systems, the distance to reach the gateway and the convenience of the device. LoraWan has the possibility to communicate in longer distances than other protocols, but still considering the rural areas this isn't sufficient. On the other hand, the data rate is too low and the traffic toward the gateway, is high which causes extra delays and low signal quality.

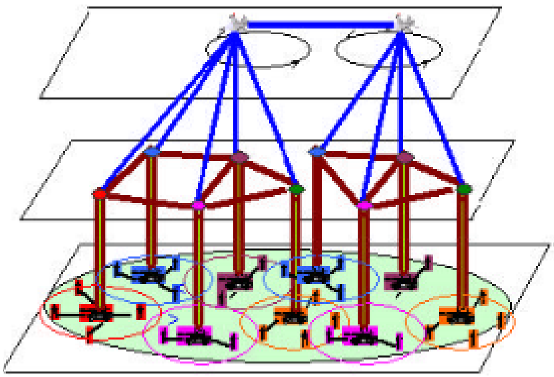
To have a better and longer communication distance we develop a new communication protocol presented here as HealthComm protocol, by proposing a new virtual infrastructure. This would enhance the communication distance range in the absence of any fixed or wireless infrastructure and overcome the main challenges of previous systems.

HealthComm Protocol

Our approach is based in our previous work on intervehicle communication protocols adapted and developed for health monitoring system. The patient's neighborhood area is divided in virtual cells. Each patient's device is considered as e node inside a certain virtual cell. The density of the nodes inside a cell is changeable, depending in the neighborhood architecture..

In this work we propose a virtual infrastructure created from distributed health monitoring devices which will be considered as nodes of an ad-hoc network. To have a low cost and controlled signal quality according to our approach the communication scheme will be a hierarchical one using up to three levels of hierarchy (only 2 levels for rural areas). (Fig.2) The first level represents by a simple health monitoring unit (HMU) that transmits to the HMU neighbor with a higher scale of hierarchy. The second level of the hierarchy is the HMU that has a certain number of neighbors (less than N), is located somewhere in the center of the cluster and will be considered as a Center Cell Node. The second level of the hierarchy when the HMU that has a number of neighbors > N, is found near the center of the cluster and will be considered as a CenterSubCell Node. The third level of hierarchy in the most populated areas will be created by the Center SubCell nodes that are neighbors and will be considered as simple Cell Nodes, by transmitting their data to the Cell Center Node located at the center of the considered area.

FIGURE 2: Multi-level hierarchical ad hoc infrastructure



The fact of using hierarchical communication scheme brings several benefits such as larger communication distances between the patient and the monitoring centers, helping people even in rural areas. The other benefit brought using the Hierarchical scheme is the low network load. According to this solution less traffic will be generated between the patients and the local health service as only the CenterCell nodes will be transmitting the data of all the nodes in their respective cell in a certain moment of time. The other benefit is the low cost of the hardware. Only the Cell Centers equipment need to have more complex design such as memory, and transmission power. Also, it is important to note that only the high hierarchy nodes (equipment) will have a higher consumed power which means that for the rest of the patient's equipment the battery will have a longer life.

FIG. 3 Communication using the Virtual Infrastructure

There is also the possibility to modify the activity of the HMUs inside the cell, which means not all patients will be monitored with the same rate. This can be completed by using the sleep-awake scheme for certain nodes in the case of people moving or not willing to be monitored any more.

According to HealthComm protocol a flexible Virtual Infrastructure is created and maintained to enable scalable and effective communications (Fig 3). The number of nodes inside a cell can be modified. In each cell only one node (HMU) will be self-chosen as a Cell Center according to its location being approximately at the geographical center of the Virtual Cell. This node will behave as a Base Station for a certain period. The hierarchical distribution of CellCenters will be transferred to the hierarchy of their costs, which means that only the equipment corresponding to the cell center need to have larger memory, processing power and battery consumption. The Hierarchical Virtual infrastructure created enables the optimization of the routing process.

At a certain rate each node updates the data from the GPS, which gives the Coordinates (x,y) for each node at a certain moment. Every node has its geographical position given by Global Positioning System (GPS). Then the higher ranked nodes transmit the data along each-other using the sequential Cell Centers as intermediate communications points and finally transmit the data to the Gateway when it reaches an infrastructure covered area as in Fig 3.The Information Management System might be a server located at Local Health Services Center that will do the process of analyzing the data collected from all the patients living in a certain area and decide about a certain action to be taken accordingly.

The equipment we propose to be used is similar to the wrist wearable equipment used in [5] including a microcontroller board with add-on sensors that will sense the patients vital signs such as temperature, oxygen levels, blood pressure etc. It will include a peripheral GPS receiver and a cellular modem.

HealthComm Benefits

As a conclusion this protocol will be more optimal to be used everywhere even in the absence of wired or wireless infrastructure, in natural emergency or under war areas. The protocol to be used gives the possibility of using tunable fine-grained sensing regarding the Data acquisition rate, threshold health alert values or node activity status. This system gives the possibility of using a mixed protocol routing scheme such as ZigBee for inside cell communication and IEEE802.11 for intracell centers communication. As we explained above the other benefit is that the hierarchical levels are tunable too, depending on the neighborhood architecture and population density ensuring good communication quality, low latency and low power consumption.

References

1. Zhang, L.; Zhu, Y.; Jiang, M.; Wu, Y.; Deng, K.; Ni, Q. Body Temperature Monitoring for Regular COVID-19 Prevention Based on Human Daily Activity Recognition. Sensors 2021, 21, 7540. [CrossRef]
2. Ullah, F.; Haq, H.U.; Khan, J.; Safeer, A.A.; Asif, U.; Lee, S. Wearable Iots and Geo-Fencing Based Framework for COVID-19 Remote Patient Health Monitoring and Quarantine Management to Control the Pandemic. Electronics 2021, 10, 2035. [CrossRef]
3. Mukhtar, H.; Rubaiee, S.; Krichen, M.; Alroobaea, R. An Iot Framework for Screening of COVID-19 Using Real-Time Data from Wearable Sensors. Int. J. Environ. Res. Public Health 2021, 18, 4022. [CrossRef]

4. Hoang, M.L.; Carratù, M.; Paciello, V.; Pietrosanto, A. Body Temperature—Indoor Condition Monitor and Activity Recognition by Mems Accelerometer Based on IoT-Alert System for People in Quarantine Due to COVID-19. Sensors 2021, 21, 2313. [CrossRef] [PubMed]
5. Bahle, G.; Rey, V.F.; Bian, S.; Bello, H.; Lukowicz, P. Using Privacy Respecting Sound Analysis to Improve Bluetooth Based Proximity Detection for COVID-19 Exposure Tracing and Social Distancing. Sensors 2021, 21, 5604. [CrossRef] [PubMed]
6. Aljohani, A.J.; Shuja, J.; Alasmary, W.; Alashaikh, A. Evaluating the Dynamics of Bluetooth Low Energy Based COVID-19 Risk Estimation for Educational Institutes. Sensors 2021, 21, 6667. [CrossRef]
7. Fernández-De-las-peñas, C.; Palacios-Ceña, D.; Gómez-Mayordomo, V.; Cuadrado, M.L.; Florencio, L.L. Defining Post-COVID Symptoms (Post-Acute COVID, Long COVID, Persistent Post-COVID): An Integrative Classification. Int. J. Environ. Res. Public Health 2021, 18, 2621. [CrossRef]
8. Zaki, N.; Mohamed, E.A. The Estimations of the COVID-19 Incubation Period: A Scoping Reviews of the Literature. J. Infect. Public Health 2021, 14, 638–646. [CrossRef]
9. Jiang, X.; Niu, Y.; Li, X.; Li, L.; Cai, W.; Chen, Y.; Liao, B.; Wang, E. Is a 14-Day Quarantine Period Optimal for Effectively Controlling Coronavirus Disease 2019 (COVID-19)? medRxiv 2020. [CrossRef]
10. Lauer, S.A.; Grantz, K.H.; Bi, Q.; Jones, F.K.; Zheng, Q.; Meredith, H.R.; Azman, A.S.; Reich, N.G.; Lessler, J. The Incubation Period of Coronavirus Disease 2019 (COVID-19) from Publicly Reported Confirmed Cases: Estimation and Application. Ann. Intern. Med. 2020, 172, 577–582. [CrossRef]
11. Lavric, A. LoRa (Long-Range) High-Density Sensors for Internet of Things. J. Sens. 2019, 2019, 3502987. [CrossRef]
12. Lavric, A.; Popa, V. Performance Evaluation of LoRaWAN Communication Scalability in Large-Scale Wireless Sensor Net
13. Lavric,A., Petrariu, A., Mutescu, P,, Coca,E., Popa,V., Internet of Things Concept in the Context of the COVID-19 Pandemic: A Multi-Sensor Application Design, Sensors 2022
14. Durresi,M.,(2016) Biosensors for Sustainable Food: New Opportunities and Technical Challenges. Comprehensive Analytical Chemistry; Continuity Publishing, Books Elsevier Ltd.
15. Zhang,P., Durresi,M., Durresi, A., (2021). Internet Network Location Privacy Protection with Multiaccess Edge Computing, Computing 103 (3), 473-490
16. M.Durresi, Wireless Sensors Networks for Food Supply Chain Monitoring, DSSH 2016, UET, Tirane
17. A. Durresi, M. Durresi, L. Barolli; Wireless Communications for Health Monitoring on Highways"; ICDCS Workshops 2007, Toronto, Canada, 37.
18. Durresi, Mimoza & Durresi, Arjan & Barolli, Leonard (2005) Inter-Vehicle Communication for Safer Highways, AINA 2005: 599-604