RM-IoT: An IoT-based Rapid Medical Response Plan for Smart Cities

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***Abstract*—Most of the health monitoring applications for response plans are used to alert or notify the users in case of emergency situations. Response plans help in overcoming an emergency scenario in case of a disaster. On several occasions, the person of interest receives medical attention, once there is an on-set of the medical condition. With current smart healthcare facilities, where there are advantages of monitoring one's health on a daily basis, a person does not need to wait to be critically ill or meet with a disaster in order to receive necessary medical services. Leveraging the advantages of smart healthcare architectures in this research, we propose a smart rapid medical response plan, which monitors the physiological signs of people in a community and gives regular feedback or alerts the hospitals accordingly. The proposed framework provides feedback on different scales by ensuring the well-being of the individuals and alerting them to be cautious towards potential health issues. The routing of these sensor networks based on the emergency level is demonstrated using an open-source tool, CupCarbon. The proposed framework was simulated using the ZigBee radio standard and the overall simulation time for 40 nodes was 95 seconds.**

***Index terms*—** Smart City, Smart Healthcare, Internet of Things (IoT), Emergency Response, Disaster Management

I. Introduction

Response plans help us analyze the possibilities of overcoming a disaster. Emergency scenarios can be based on environmental disasters such as oil spills, poisonous gas leakages, cyclones, or epidemic breakouts such as malaria or dengue [1], [2], [3]. In the case of emergencies based on environmental parameters such as floods, earthquakes, and cyclones, it is important to design an effective fast response plan which would help in reducing the damages caused and save lives of thousands of people. In modern times, it is impossible to have a person assist someone all the time. At the same time, with the latest healthcare technologies, it is not very efficient to wait for a person to fall critically ill in order to cure them of disease. Analyzing physiological parameters continuously or periodically can help in overcoming such disasters.

The Internet of Things (IoT) helps in connecting many devices together, where each device is recognizable. In a cyber-physical world, many applications requiring real-time response and virtual objects are deployed. Some of the applications include surveillance [4], agriculture, healthcare, security, vehicular technologies, etc. [1], [5]. Architectures and elements used to deploy a wireless network can be easily merged with sensors to form an IoT network. Significant investments have been made by public and private agencies towards improving communications between healthcare providers and non-profit organizations when a disaster strikes [6].

Fig. 1. Conceptual Overview of the proposed RM-IoT, a Smart Rapid Medical Response Plan

Figure 1 shows a cloud-based sensor system deployed in households of a community. At the sensor level, the system is a custom-built light-weight wearable smartwatch that contains a temperature sensor and heart rate sensor where each person's parameters are monitored along with their ID. Based on the pattern observed from the wearable of individuals, each household is graded as critical, high priority and warning. Many such sensors are connected together in the community and a feedback system is provided. If someone is having a prolonged increase or fluctuations in temperature, the corresponding correlation of heart rate values is taken at that particular instance. The smart response plan helps in alerting the family and the health care providers and alerts the nearest medical facility or listed healthcare professional at the earliest. The proposed framework is modeled in CupCarbon [7]. CupCarbon is a wireless sensor network design and simulation tool that offers simulating environments for smart cities [8].

The organization of this paper is as follows: The novel contributions of this paper are described in Sec. II. A broader perspective of the smart response plan for smart cities is presented in Sec. III. The literature on existing research work for modeling response plans is discussed in Sec. IV. An overview of the system-level modeling of the response plan, which includes a brief discussion on the A* algorithm, is given in Sec. V. The implementation of the designed blocks along with simulation results and the corresponding limitations are discussed in Sec. VI. Conclusions and directions for further research are given in Se. VII.

II. Novel Contributions

One of the biggest advantages of the Internet of Things is the remote assistance it offers through cloud connectivity. In order to benefit more from this technology, this paper proposes an IoT-based rapid response plan, RM-IoT, which helps in improving the overall health and living conditions of people in a community. The proposed system helps in seamlessly monitoring the vital signs, therefore reducing the total amount of money spent in a family towards wearables and other monitoring devices. As the data is being collected from different nodes in a community, they are further grouped depending upon the severity of the parameters or the condition. In the proposed system, along with addressing the critical scenarios, a solution to address high priority alerts is also given. This is done in order to keep the users well informed of their health and alert the medical facilities about potential high-risk scenarios. A response plan based on the A* (A Star) search algorithm to find the nearest hospital in case of any emergencies is modeled. The clustering of data based on their priority is shown in CupCarbon. The proposed framework is modeled in CupCarbon using Senscript and the performance is analyzed in terms of energy efficiency and battery life.

III. Smart medical response plan in Smart cities: A Broad Perspective

In the present world, monitoring physiological activities is a convergence of several technologies and business verticals. Wearable medical sensors are being widely used to monitor physiological signals such as heart rate, blood pressure, blood oxygen concentration, etc. In recent years, sensors deployed in hand-held devices such as mobile phones or tablets have also been used for monitoring vital signs. In spite of the wearable industry continuously improving with multiple sensing modules and highly accurate algorithms, there exist a few limitations in making the entire community health aware or healthier. This is because the wearables are concerned only in improving the individual's health and if the entire community needs to benefit, each one needs to own a wearable, which would increase the total cost budget. Figure 2 shows the block diagram of the proposed medical response plan.

The monitoring unit is a light-weight custom-built wearable with sensors that are used for monitoring the vital signs of the users and a processor that can be used to schedule the data acquisition. The processor also facilitates transmitting the sensor data to the IoT cloud through the WiFi module. All the sensor data along with the respective time stamps and IDs are sent to the Node Clustering Unit (NCU), where at first nodes of similar locations are grouped together. This is done because it makes the computation of the shortest path from the source to the destination easier. After grouping the nodes, the optimal parameters are compared to classify the data into critical, warning and safe. The output of the node clustering unit is sent to the Path Designer Unit (PDU), implemented in the IoT cloud, where the grouped data is given as input to the pathfinder along with the database of the nearest medical facilities.

IV. Related Prior Research

In [9], five strategies for designing the response plan in the case of natural disasters such as hurricanes, tornadoes, earthquakes etc. are presented. A response plan analyzing the soil erosion and water loss crisis is proposed in [10]. An emergency response plan based on oil spill has been proposed in [11]. Similarly, an emergency response plan for smallpox attack, which would require mass vaccinations is proposed in [12]. An analysis of information technology components in case of an emergency is given in [6]. In [13], an emergency predication based on the forecast updates is proposed. A fire simulation model has been introduced in [14] where the spreading of fire is analyzed as a stochastic process. A fuzzy based evaluation model for an emergency response plan has been proposed in [15]. The A* algorithm has been used in pathfinding for a perfect maze [16] and a hexagon-based environment [17]. A hybrid approach based on fuzzy logic and A* to improve the life-time of wireless sensor networks has been proposed in [18]. In [19], a PSO-based packaging algorithm for an IoT based system is proposed. With help of these machine learning techniques deployed in wireless sensor networks, seamless monitoring solutions have been developed [20]. A respiratory monitoring system based on human activities is proposed in [21].

V. System level modeling of Smart Medical Response Plan

A. Health Monitoring Unit in Smart Cities

In any response plan, the monitoring parameter is the primary focus, based on which the severity of the response plan can be decided. The monitoring parameters considered for the Health Monitoring Unit in the RM-IoT framework are temperature and heart rate values. Temperature values can play a vital role in determining one's overall health [22].

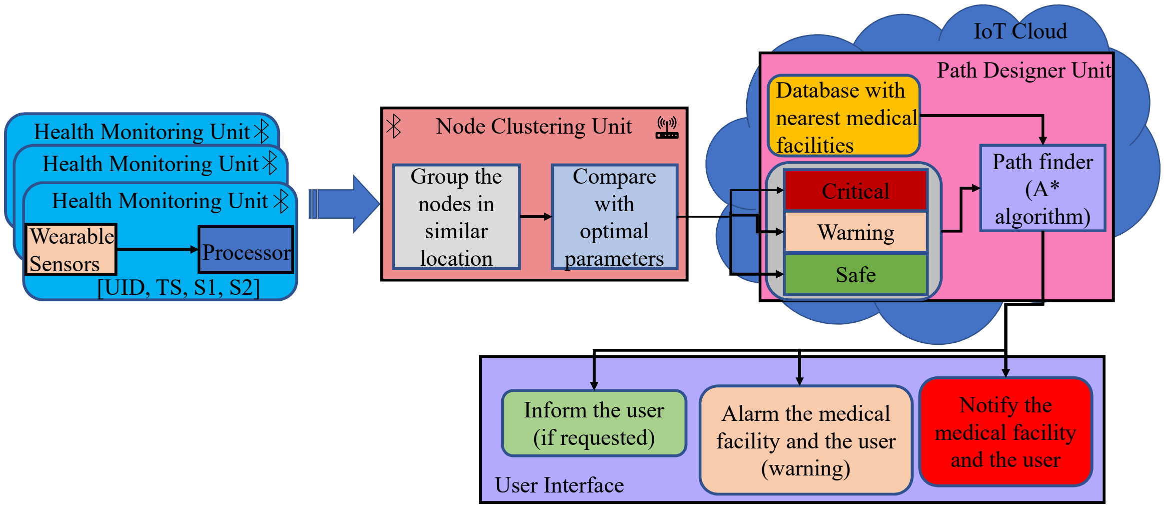

Fig. 2. Basic Block Diagram of the Proposed Rapid Medical Response Plan.

Correlating the temperature sensor values along with the heart rate values can help in monitoring underlying conditions and address critical conditions immediately.

B. *Algorithm for Smart Response Plan*

In a highly interconnected smart city, countless nodes can be used anywhere for anything: from functioning as a medium for wireless signals and data to facilitating communication between different devices. The use of nodes is undoubtedly useful for quick data transfer, and an algorithm can be applied to determine the fastest, or most optimized, path from the source (in this case the patient's place of residence) to the destination (the medical facility) in an intricate network of nodes found in a smart city.

The algorithm used for this research is the A* ("A Star") Algorithm, a highly successful pathfinding algorithm for finding the shortest distance between nodes [23]. This algorithm is a best-first search algorithm and is an extension of Dijkstra's algorithm. Figure 3 shows an example of the best-first search computation by the A* algorithm from start node to end node.

The A* algorithm takes into account three main values during execution: total weight ($f(n)$), cost of the path from the start node to n ($g(n)$), and the heuristic value, or the cheapest path to the destination ($h(n)$). The heuristic distance, for the purposes of the algorithm implementation, can be thought of as the Euclidean distance between n on the plane to the destination on the same plane. The total weight value $f(n)$ is sum of $g(n)$ and $h(n)$ as given in the following equation:

$$f(n) = g(n) + h(n) \quad (1)$$

The total weight obtained at each node is the deciding factor for optimization. When the algorithm is implemented to compute the shortest path from source to destination, the nodes are divided into three groups: open (fringe), closed, and uninitialized (unevaluated). Table I shows the closed, open, and unevaluated list of nodes in the A* illustration shown

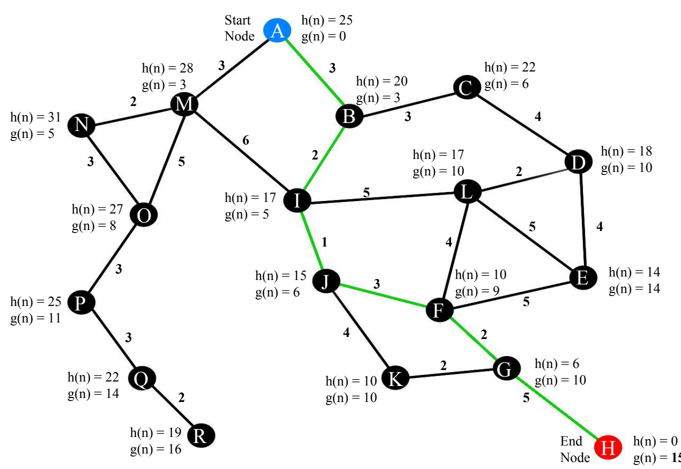

Fig. 3. Illustration of A* Algorithm to Compute the Shortest Path between Start and End Node.

in figure 3. When the start node and destination node are determined as A and H, the shortest path between them is evaluated. This cheapest path offers the fastest travel time from the start node to the destination, assuming the data transfer speed is the same across all possible paths. From the patient's residence to the medical facility, the path proposed by the A* algorithm will allow for the shortest time and least energy used, avoiding unnecessary nodes and data transport.

VI. Implementation and Validation of Smart Response Plan

A. *Custom-Built Health Monitoring Unit*

The Health Monitoring Unit and Node Clustering Unit was designed with the help of commercially off-the-shelf components. The health monitoring unit was designed using an MCP9808 temperature sensor, and MAX30102 Pulse Oximeter as a wearable. The Node Clustering Unit was implemented using a single-board computer, the Raspberry Pi 3+. The data

TABLE I
CHART REPRESENTING THE CLOSED LIST, OPEN LIST AND UNEVALUATED NODES FOR THE ILLUSTRATION GRAPH.

Closed list nodes	Fringe (Open) list nodes	Unevaluated nodes
A (Start node)	M	D
B	C	N
I	L	O
J	K	P
F	E	Q
G		R
H (Destination)		

collected from the wearable through the single board computer is later processed using the IoT cloud.

B. Evaluation of Platforms for Response Plan Implementation

The response plan was modeled in Cupcarbon. With the help of the built-in functionalities, such as the ability to deploy multiple nodes and the ability to analyze energy efficiency, battery levels, power consumption, and other simulation parameters, the overall efficiency of the system is analyzed. Response plan modeling using the A* algorithm in MATLAB® is unfortunately not suitable for the tasks at hand. Because MATLAB® is very efficient with matrices (the software is meant to evaluate entire matrices rather than numbers one at a time), the A* algorithm and other single source graph search algorithms can be best used for navigating through obstacles in an effort to reach the destination. This is because the entire matrix can be described as a map, and every entry in the matrix can be evaluated and assigned as an obstacle or an open point.Figure 4 shows the MATLAB® implementation of A* algorithm as given in [24]. The grid is not identical to a Cartesian coordinate plane, however; the y axis values grow larger near the bottom. The MATLAB® approach to implementation of A* algorithm was different from that of CupCarbon's. Due to the matrix style layout and grid, the implementation focused on the recognition and avoidance of individual obstacles constructed from points. As the algorithm code was compiled and ran with start point, endpoint, and obstacles defined, the output highly resembled a maze, as the program tried to find the shortest path between the two points while taking into account obstacles blocking its movement along the way. Meanwhile, the CupCarbon algorithm focused on finding the shortest, cheapest path through connected nodes, with movement limited to the defined paths between adjacent nodes. The MATLAB® approach allowed relatively free movement, the path defined by specific points or entries in the matrix.

C. Prototype of Rapid Medical Response Plan in CupCarbon

1) Optimized Path finding: A prototype of the smart response plan based on the A* algorithm, implemented in CupCarbon is shown in Figure 5. The nodes are the sensors or edge devices that connect to the Internet which help in collecting the data at the top level. In a real-time implementation, these nodes can also be the hub devices under which multiple such

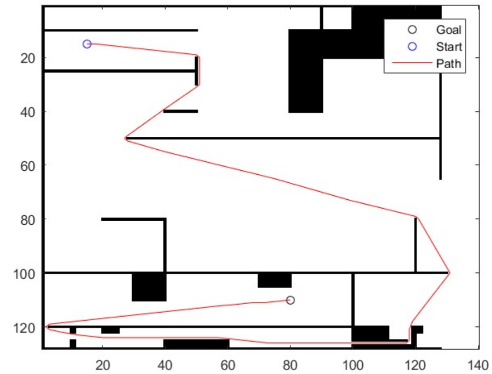

Fig. 4. MATLAB® Implementation of the A* Algorithm.

sensors can be present in the hierarchy. Table II shows the evaluation of each node at a given instance.

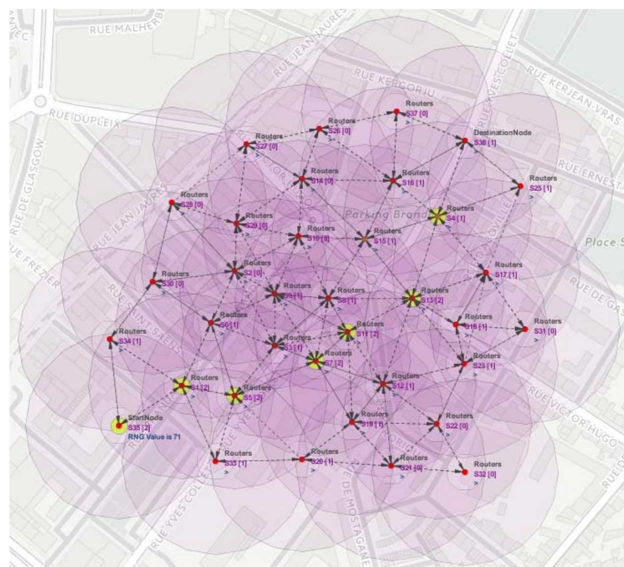

Fig. 5. A* algorithm modeled in CupCarbon

TABLE II
CHART REPRESENTING THE CLOSED LIST, OPEN LIST AND UNEVALUATED NODES FOR THE CUPCARBON IMPLEMENTATION.

Closed list nodes (MY=2)	Fringe (Open) list nodes (MY = 1)	Unevaluated nodes (MY=0)
S35 (Start node)	S34	S28
S1	S33	S29
S5	S6	S30
S7	S9	S2
S11	S3	S27
S13	S20	S26
S4	S19	S10
S36 (Destination)	S8, S12, S23, S18, S15, S17, S16, S25	S14, S37, S21, S32, S22, S31

When the A* algorithm is implemented, node S35 is considered as the start node and node S36 is considered as the destination node. The shortest path from the start node to destination node is evaluated. At each instance, the open (fringe) node and the unevaluated nodes are tabulated to understand the algorithm. It can be seen that the shortest path from the start to destination node is determined with the minimal amount of nodes in between them.

While the overall efficiency of the system is analyzed, it is important to consider power analysis. A visual representation of the energy and battery level consumption analyzed at each and every node is shown in figure 6. In this analysis, initially the battery levels were set to an arbitrary 2 Joule capacity for better viewing purposes. The particular A* algorithm iteration analyzed lasted a total of 94.93 seconds as represented in the power consumption analysis graphs. This iteration was based on simulation parameters set to 1 second for arrow and simulation speeds (1000 milliseconds). The buffer meter can be ignored in this figure as it is not required for analysis.

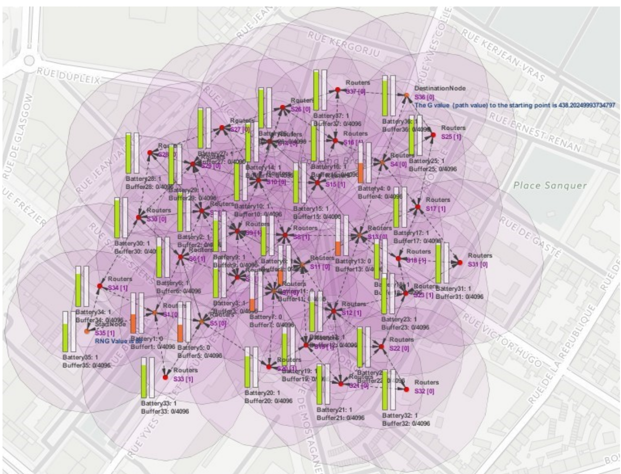

Fig. 6. Battery Analysis of the A* Algorithm at Each Node.

2) Node Clustering Based on Parameters: The management of a large number of health monitoring units in various residential environments can be overwhelming at times. Measuring patient temperature and heart rate data, and assigning the data to an individual node for countless patients can be better facilitated through basic node clustering. As an addition to optimized algorithmic pathfinding, clustering patient data in the form of nodes based on an arbitrary measurement taken over an interval of time was also designed using the CupCarbon software. This basic implementation provides a useful role in data management and organization, grouping all nodes into three categories: safe, warning, and critical. Using a random number generator between one to one hundred as the arbitrary deciding factor, each node's random value is changed and assessed every second. If the value is over the arbitrary value of 80, the node emits a red-colored LED with a printed "critical" statement. If the value is between 61 and 80, inclusive, the node emits a yellow-colored LED with a printed "warning" statement. Finally, if the value is equal to or less than 60 the node emits a green colored LED with a printed "safe" statement. As mentioned before, every node is reevaluated every second, and the loop repeats infinitely. Figure 7 shows the clustering of nodes into critical, warning, and safe, depending upon the values of the parameters. Table III gives an evaluation of the proposed rapid medical response plan in CupCarbon. The radio used for modeling this framework was ZigBee (IEEE 802.15.4) which is common in low-rate wireless personal area networks.

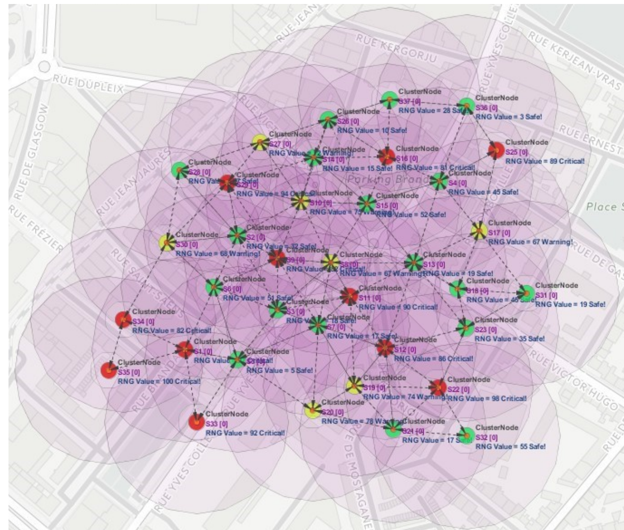

Fig. 7. Visualization of Node Clustering Based on the Parameters using CupCarbon.

TABLE III
SMART RESPONSE PLAN EVALUATION IN CUPCARBON.

Characteristics	Methods/standards/values
Response plan algorithm	A* search algorithm
Number of devices	40
Radio Standard	ZigBee(802.15.4)
Simulation Time	95 seconds
Number of SENT messages	124
Number of RECEIVED messages	230
Number of ACK messages	17
Number of LOST messages	0
Computational Platform Specifications	
Processor	Intel Core i5-7200 CPU running at 2.50 GHz
Operating System	Windows 10

VII. CONCLUSIONS AND FUTURE RESEARCH

In this work, a framework for a rapid medical response plan has been proposed. The proposed framework was implemented in CupCarbon, which helps in analyzing the real-time limitations and emergency scenarios. The software tool Cupcarbon had certain limitations in implementing the proposed algorithms. Many algorithms rely on global variables and data storage, which CupCarbon is unable to achieve efficiently. The program utilizes node intercommunication only through sending and receiving messages between adjacent connected nodes. Therefore, in order to implement advanced algorithms, extensive effort was required to create a program with these limitations in mind. The proposed framework would be easier to implement, as it requires minimal resources. Community-Based remote assistance helps in improving the quality of life and reduces the amount of money spent on individual wearables. This framework helps in keeping every user aware of their health, as people grouped under warning and safe are also informed of their status. Future research involves implementing a similar framework with other monitor solutions such as respiratory monitoring, sleep monitoring, etc.

VIII. Acknowledgment

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