Received: 19 April 2021 | Revised: 4 December 2021 | Accepted: 5 December 2021

DOI: 10.1049/htl2.12020

Healthcare Technology Letters

The Institution of Engineering and Technology WILEY

ORIGINAL RESEARCH PAPER

Remote health monitoring system using heterogeneous networks

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Abstract

This paper presents the implementation of a remote health monitoring system by using Heterogeneous Networks (HetNet), in which remote patients' vital data can be sent to the proximate hospital with very low end-to-end latency. To carry out the aforementioned process, patients' statistics are delivered initially from Wireless Body Area Network (WBAN) to the patients' mobile phone by using ISM band. Then, from there, contemporary networks make use of single wireless network alone to send the patients' data to the nearest hospital (even though there are multiple networks in a terrain). But, this particular network may have so much of end-to-end latency as a consequence of lack of resources in the network. However, in the proposed work, all the available heterogeneous Radio Access Technology (RAT) networks carry multiple patients' statistics to the nearest hospital by using either the RAT's free channels (in licensed band) or white space channels. Further, in order to reduce the latency in the proposed system, a novel hand-off method is suggested in this paper by exploiting SDR features. Moreover, simulation results reveal the effectiveness of the proposed system in terms of end-to-end latency and spectral efficiency.

1 | INTRODUCTION

In recent times, India is facing a high rate of cardiac diseases. Besides, cardiac diseases have become significant causes of mortality in India, both across the rural and urban populations [1–5]. When those people (enduring diseases) go to isolated places and if they get the symptoms of heart attack in that isolated place, then using Remote Health Monitoring (RHM), patients' vital information (i.e. sensed data sensed by the sensors placed on the body of the patient) is communicated to the nearby hospital very fast so that doctor could give suggestions to the patient before the ambulance arrives to the patients' location. However, there is an enormous scope to improve "Remote Health Monitoring" by enhancing its accuracy and reducing end-to-end latency.

In existing RHM systems, patients' data was transmitted either through the same wireless network that belongs to the same operator [6–19] or through Wireless Sensor Networks (WSNs) [20–24]. This may take more time because of lesser throughput or non-availability of resources in that particular wireless network. Further, the transmission of multiple patients' information through the same wireless network may lead to disaster because of higher latencies involved through existing transmission methods. This happens because of the limited number of channels available within that individual wireless network. Further, unavailability of the Base Station (BS) of a particular wireless network in certain places may hinder the delivery of data. In contrast, proposed work removes this impediment and delivers each patients' vital information very swiftly to the doctor by using multiple heterogeneous networks. This becomes feasible by splitting the entire data into multiple chunks and transmitting all those chunks of data through different reachable wireless networks. Additionally, in case of inaccessibility of a specific wireless network's BS, chunks of data can be distributed through the other attainable wireless networks' BSs. Consequently, usage of heterogeneous networks reduces latency when compared to the deployment of single wireless network alone. Moreover, proposed work reduces the latency for doing the hand-off between adjacent RATs (or Radio Access Technologies) by employing the separate control white space channel and using Software Defined Radio (SDR). Thus, the proposed system can provide enhanced health care services to remote areas of developing countries where there is a shortage of an effective specialized doctors. Additionally, by introducing this scheme, patient mortality caused by cardiac diseases will be significantly reduced.

The rest of this paper is organized as follows. Relevant preceding work is inferred in Section 2. Besides, the methodology of the proposed system is discussed in Section 3. Subsequently, Section 4 presents simulation results for reducing end-to-end latency and to enhance spectral efficiency. Ultimately, conclusion is deduced in Section 5.

2 | RELATED PRECEDING WORK

In the literature, several research works have been proposed for "Remote Health Monitoring" (RHM). For instance, [25, 26] makes use of Internet of Things (IoT). Here, patients' vital data is sent from sensors to a connector (like PDA and Laptops) by using Bluetooth technology. Afterwards, connectors send the sensed data to a remote site by using one of the cellular technology.

Analogously, in [27], driver's drowsiness is detected by sensing the eye movements of the driver (so as to alert the driver while driving).

Similarly, [7–19, 28] describes the Quality Of Service (QOS) issues for real-time RHM system accomplished through a specific wireless network. However, QOS is facilitated here by performing optimal resource allocation in a particular wireless network (Even though data is received from other heterogeneous network, data is to be transmitted further from this exclusive wireless network only after implementing its resource allocation fully). In spite of this, hand-off is not considered in [14–19, 28]; whereas hand-off is investigated in the present paper.

Equivalently, [29] proposes wireless sensor network architecture for patient monitoring. But, sensor networks try to preserve the energy to the maximum extent possible. Further, many sensor relays should be installed to transmit the sensed data to the far away located remote coordinator.

Conversely, when there is more than one wireless network available to communicate the perceived patients' videos to the hospital, using only one specific wireless network for transmission (as in contemporary systems) may not reduce end-to-end latency to the desired extent [19, 30–36]. In consistence with this, interconnection between two different networks like Wi-Fi and 3G/4G networks is detailed in [37–40]. However, the proposed work can handle any number of interconnections, in contrast to the present-day technologies. Additionally, in the surrounded networks, if any network is not having enough channels to transmit the patients' sensed videos, that network uses white space channels to send the videos. Correspondingly, every RAT is equipped with SDR characteristics. Hence, SDR (installed in RAT) chooses the appropriate specifications from among various modulations, different channel coding techniques etc. as per the strengths of the channels. Consequent to this novelty used, the proposed work meets the basic requirements of 5G, that is, low end-to-end latency, high spectrum efficiency [41, 42], and also facilitates higher data rates through the connection of the existing diverse radio networks.

3 | METHODOLOGY

In the proposed remote health monitoring system, three scenarios are designed for fast and efficient data transmission operation.

3.1 | Experimental method for reliable heterogeneous communication of the patients' statistics

Body Area Network (BAN) of the patient measures the patients' vital statistics. (It is assumed here that BAN is perfect in every sense. That is, BAN has adequate energy and sufficient Band width for its implementation). In BAN, sensors placed in/on the body of the patient conveys the patient's statistics (or video) to the cell phone. Meanwhile, size of measured data that is to be transmitted from patient's cell phone to the hospital is more than mega bytes. In this fashion, multiple patients' information is to be conveyed. In order to communicate this much amount of data using the single wireless network requires a large number of resources. Hence, patient sensed data (or videos) is split into multiple parts, and these parts are transmitted through various heterogeneous networks that are there in between cell phone and hospital. Instead of sending the entire sensed data through a single wireless network, sending the data through multiple heterogeneous networks reduces the end-to-end latency profoundly.

In a particular location, m RATs (RAT1, RAT2, …, and RATm) are available to send the patients' data. Here, cell phone or RAT decides about the number of RATs that are in its surroundings. To apprehend this, cell phone/RAT broadcasts its control signal on white space channel. RAT that receives this control signal communicates back on the other white space control channel informing that it is available for the required data transmission. Thus, cell phone/RAT resolves about its circumambient RATs.

For instance, if the patient's cell phone detects that two heterogeneous networks (RAT1 and RAT2) are there nearer to it (as depicted in Figure 1), then sensed data is split into two parts, with the first part transmitted to RAT1 and the second part relayed to RAT2.

In similar fashion, RAT1 detects that there are n RATs surrounding to it. Then, RAT1 divides the received data part into n chunks and then conveys n^{th} chunk to the n^{th} surrounded RAT by using different channels. Here, size of the n^{th} fragmented data chunk depends on the consecutive parameters: (a) transmission capability of n^{th} RAT, (b) number of channels (either its own channel or white space channel) that can be assigned for n^{th} data chunk transmission & (c) allotted channel strength determined based on the parameters like interference effect on the chosen channel, channel attenuation etc.

If unpremeditatedly, RAT1 does not have enough free channels to transmit the 3rd chunk to RAT3, then RAT1 uses white space channels to send that 3rd chunk to RAT3 as shown in Figure 1. However, the chosen white space channel should not

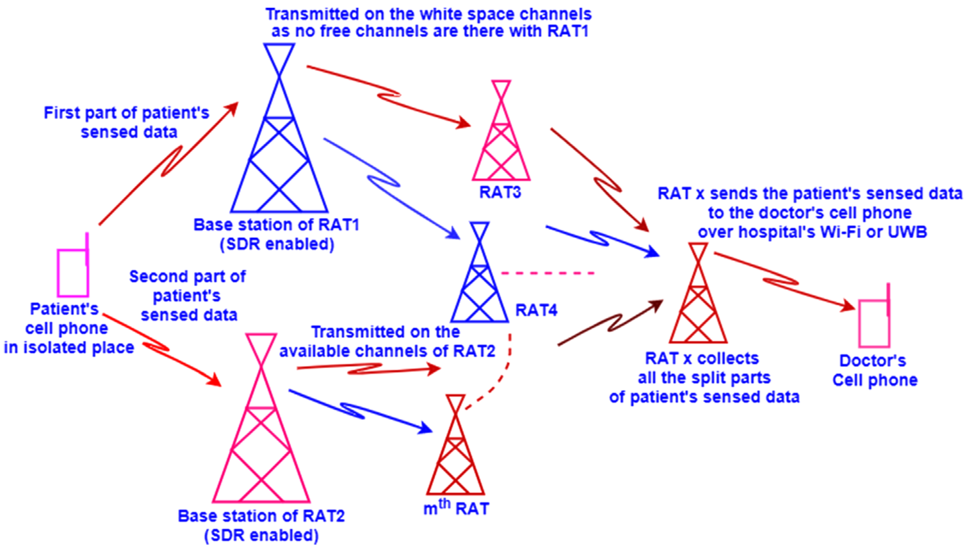

FIGURE 1 Patients' sensed data transmitted through heterogeneous networks

TABLE 1 n^{th} chunk data packet sent from RAT1 to RATn

Source address (cell phone address followed by RAT1 address)	RAT1 received which part of patients' sensed data (In Figure 1, it is 1st part of patients' sensed data)	Indication that it is n^{th} chunk of the RAT1's received data part	n^{th} chunk of transmitted data (along with the data size of the n^{th} chunk)	Final destination address (hospital's cell phone address)	Temporary destination address (RATn address)	Information related to the data transmission (like channel utilized for data transmission, modulation used, error coding applied etc.)

create more than the endurable interference to primary users [41]. Besides, as the RAT avails its freely available channels apparently for these transmissions, RAT does not disrupt its own activities. Moreover, its resources are not wasted for implementing the proposed work. The format for sending the n^{th} chunk data from RAT1 to RATn is given in Table 1.

Similarly, using the above mentioned procedure, all the RATs transfer their received data chunks to their adjacent heterogeneous RATs. Finally RATx which is adjacent to the hospital accumulates all the data chunks (based on the number of the received segmented chunk as per Table 1) and then form the final data. This converged data is sent to the hospital's Wi-Fi or UWB (Ultra Wide band) from which data is delivered finally to doctors' cell phone and ambulance cell phone.

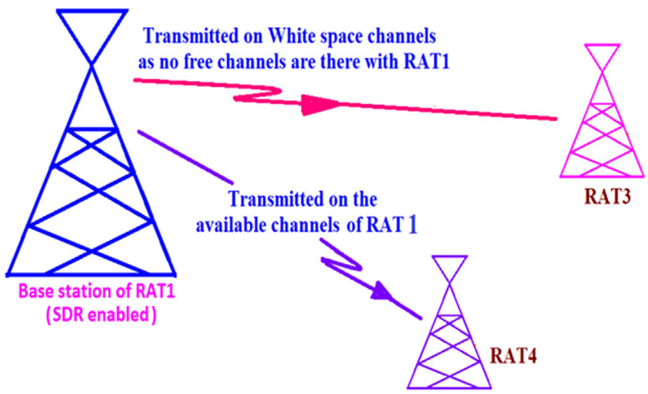

FIGURE 2 Usage of white space channels in heterogeneous communication done through divergent RATs

3.2 | Heterogeneous communication using white space channels

During the transmission of patients' sensed data, if RAT1 finds out that there are m number of multiple dissimilar RATs around it, then that RAT1 divides the received data into m fragments and transmits m^{th} fragment to the surrounded m^{th} RAT. For illustrative purposes, RAT1 has divided the received data into m = 2 fragments as shown in Figure 2. But, RAT1 has enough channels to communicate with RAT4 alone and does not have adequate channels to communicate with RAT3. Then, RAT1 uses the available channels to transmit the 1^{st} fragment to RAT4. However, RAT1 delivers the 2^{nd} fragment to RAT3 using white space channels.

Moreover, if the distance between RAT1 and RAT3 is more, then RAT1 can't use its own channels. This is because of RAT1's retaining channels having more attenuation when data is transmitted for longer distances using these channels. In that case, RAT1 can use white space channels so as to transmit its signals for longer distances without much attenuation. Additionally, if no RAT (or no wireless network's coverage) is there in the surrounding region of RAT1, then seamless communication can be continued further by sending the sensed data through

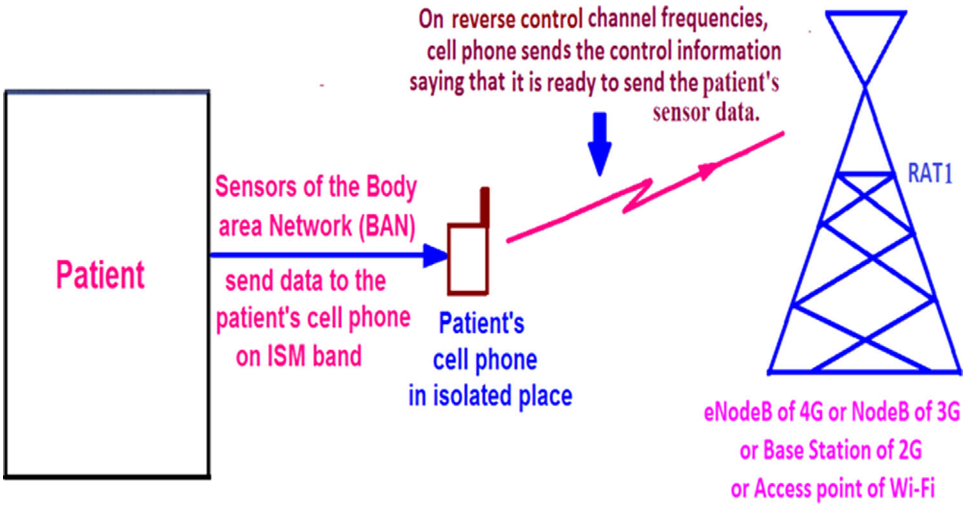

FIGURE 3 Sending the patients' data from the Wireless Body Area Network (WBAN) to the cell phone

whitespace channels. As white space channels travel for longer distances, RAT (of a wireless network) located in farther regions from RAT1 can now be used to retain the seamless communication.

3.3 | Reliable model for the hand-off between heterogeneous wireless networks

If the patient is in isolated place; then also patient's sensed videos have to reach the hospital. Despite everything, that isolated place may not be there in the coverage area of any wireless network. To check if the cell phone is in the coverage area of the cellular network, cellphone sends its control information on the Reverse Control Channel (RCC) to its cellular network (RAT1 in Figure 3). Moreover, subsequent events can happen:

If cellular network (or RAT1) is there nearby to the cell phone location (or patients' location) and RAT1 has enough free channels to further transmit the patients' data, then RAT1 responds to cell phone on the Forward Control Channel (FCC) that cell phone can send its data to RAT1 now. Then, cell phone transmit all of its sensed data on the RAT1 mentioned frequency channels to the RAT1. Subsequently, RAT1 forwards the data further towards the final destination (or Hospital). This is presented in Figure 4.

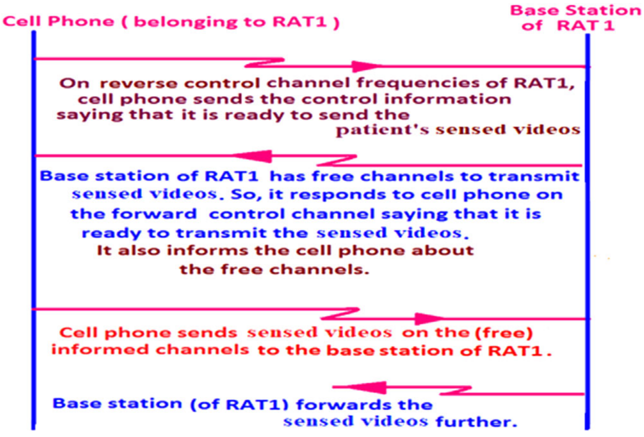

FIGURE 4 Flow diagram for patients' data transmission when cellular network (or RAT1) has enough free channels

When cell phone requests the nearby cellular network (or RAT1) that it has data to send, RAT1 informs to the cell phone on the forward control channel (FCC) that it does not have any free channels to send all of the patients' information (or) RAT1 does not respond as RAT1 is far away from the patients' location. This is done as revealed in Figure 5.

But, cell phone has to transmit the patients' data immediately even though RAT1 does not have any free channels. For this reason, cell phone uses Cognitive Radio networking features to connect to the nearest base station (of any RAT). Concurrently, it is inferred that either RAT or cell phone updates its data base list of white space channels frequently, by querying the remotely maintained spectrum database [43].

Moreover, it is deduced here that base stations of RAT's or Gateways are equipped with VHF/UHF frequency receiving/transmitting antennas. In addition, base stations are SDR controlled, as SDR controlled base stations can use VHF white spaces for doing heterogeneous communication. Furthermore, VHF white space control channel is used by all RATs (to inform to the other RATs about which white space channels are used for data transmission) and this control channel is not used for transferring data.

As illustrated in Figure 5, cell phone sends the control packet specified in Table 2 on white space control channel.

As VHF frequencies can reach for longer distances even for smaller transmitted powers, control packets sent on the white space control channel reach to the RATs that are in faraway places also. After seeing this control packet, RATs that are ready to send the patients' sensed videos give the reply on the white

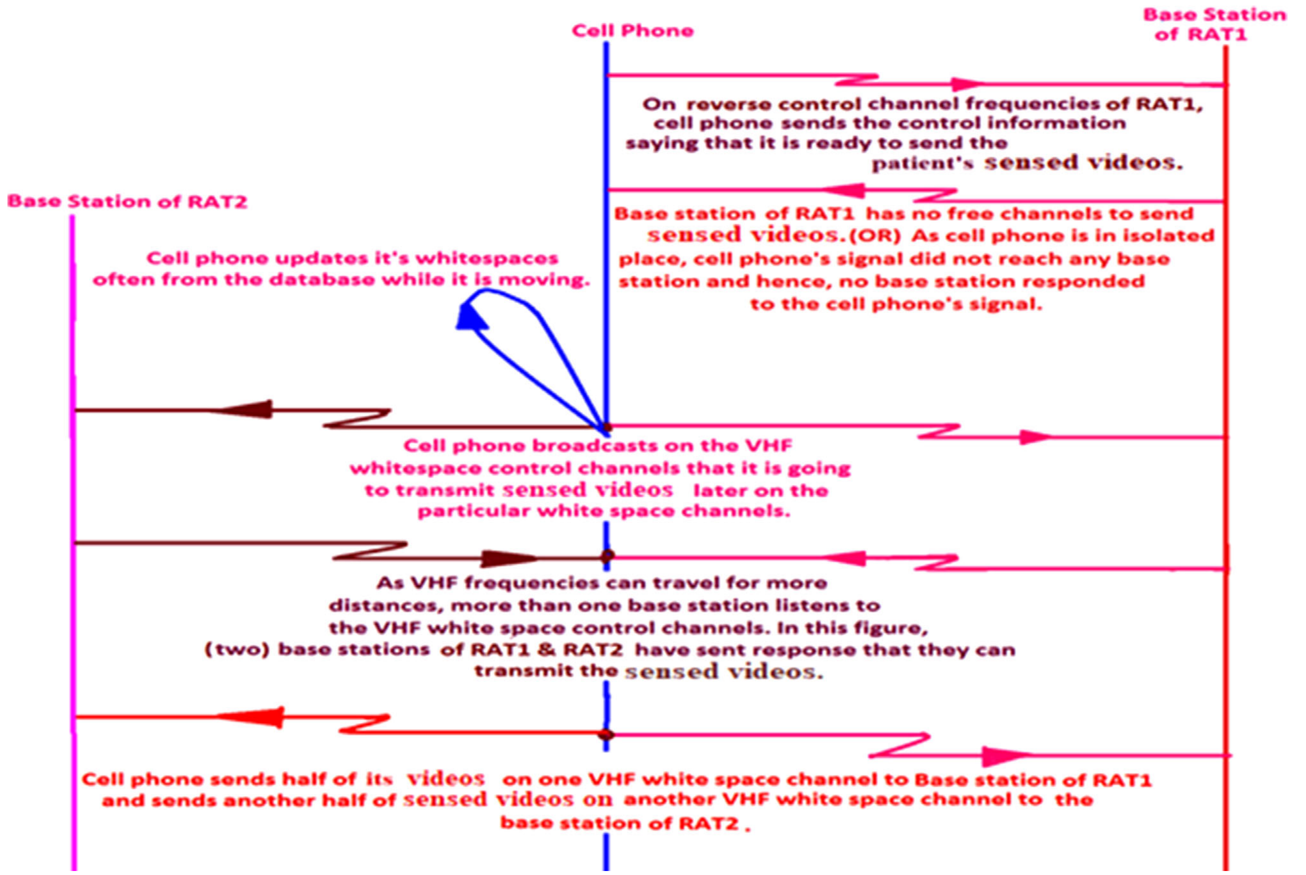

FIGURE 5 Flow diagram for patients' data transmission when cellular network (or *RAT* 1) has no free channels to transmit the patients' sensed data further

TABLE 2 Control packet to be sent from cell phone to multiple RATs

Source address (cell phone number)	Destination address (hospital's phone number)	Amount of data chunk to be sent to the destined RAT along with the addresses of the intermediary RATs that are communicating	White space channel numbers, (on which cell phone can send the patients' sensed data later)	White space channel to be used for sending back the reply (control Packet) to the cell phone	Information related to the control packet transmission (like error coding applied etc.)

space control channel (which is given in the fifth field of Table 1 control packet) to the cell phone.

4 | SIMULATION RESULTS AND DISCUSSION

In this section, results demonstrating the use of multiple heterogeneous RATs in improving the end-to-end latency and spectral efficiency are discussed. These results are validated in Matlab software.

It is assumed here that every RAT is equipped with SDR features. Hence, if a RAT is availing a channel to deliver its chunk of data, then based on the strength of that channel (i.e. channel parameters like its noise, impact of other channels on this particular channel etc.) ; RAT adopts its error-correcting parameters, modulations, along with others. For instance, transmission on more robust channel can be accomplished by utilizing higher order modulations like 64-QAM, 256-QAM etc. Conversely, lower order modulations compatible to BPSK and QPSK are exploited for weaker channels, in order to facilitate error-free decoding at the receiver.

Further, SDR is adept at selecting the better channel from among the available channels (either to evade Interference or to obtain higher data rates). Besides, if all the channels are weaker channels; then SDR chooses white channels for transmitting its data. In this way, SDR endeavours to reduce the bit error rate.

It is assumed here that M locations are there in between the patient's cell phone and hospital. Herein, $y = 1, 2, \cdots, M$ refers to the y^{th} particular locality. Additionally, 'm_y' heterogeneous RATs are presumed to be there in y^{th} specific territory. Moreover, x^{th} heterogeneous RAT in y^{th} explicit region can render B_{xy}

TABLE 3 Improvement of the latency of the proposed heterogeneous networking system over the usage of single wireless network as in [14–18] (Here, m_y heterogeneous RATs are there in y^th specific territory. However; y = 1, 2 (==> M = 2) locations are assumed to be there in between patient's cell phone and the hospital. In any case, x^th heterogeneous RAT in y^th explicit region can transmit R_{xy} bits/s; whereas single wireless network transmits the data with the rate of R_S bits/s in all M locations. Further, number of bits to be sent from the patient's cell phone to the hospital is: N = 10 mega bits)

S.No.	m_1 number of RATs in first location render the latency of $L_1 = \frac{N}{\sum_{x=1}^{m_1} R_{x1}}$ s	m_2 number of RATs in second location offer the latency of $L_2 = \frac{N}{\sum_{x=1}^{m_2} R_{x2}}$ s	Heterogeneous networking system takes $L_H = \sum_{y=1}^{M=2} L_y$ s time to transmit N bits in M = 2 locations.	Utilization of single wireless network in each location provides $L_S = \frac{N}{R_S}$ s latency.	Swiftness of the heterogeneous network over the single wireless network in dispatching the data by $M \times L_S$ - L_H s.
a)	m_1 = 3 RATS yield R_{x1} = {100 K, 50 K, 50 K} bps. ==> L_1 = 50 s	m_2 = 4 RATS provide R_{x2} = {10 K, 50 K, 25 K, 75 K } bps. ==> L_2 = 62.5 s.	$L_H = L_1 + L_2$ = 112.5 s.	Single Wireless Network in each location contributes R_S = 20 Kbps. ==> L_S (in each location) = 500 s.	Swiftness of data delivery by Heterogeneous Networking System over Single Wireless Network = 887.5 s.
b)	m_1 = 2 RATS yield R_{x1} = {30 K, 60 K } bps. ==> L_1 = 111.11 s.	m_2 = 3 RATS provide R_{x2} = {20 K, 10 K, 20 K } bps. ==> L_2 = 200 s.	$L_H = L_1 + L_2$ = 311.11 s.	Single Wireless Network in each location contributes R_S = 20 Kbps. ==> L_S (in each location) = 500 s.	Swiftness of data delivery by Heterogeneous Networking System over Single Wireless Network = 688.89 s.
c)	m_1 = 4 RATS yield R_{x1} = {50 K, 50 K, 10 K, 40 K} bps. ==> L_1 = 66.67 s.	m_2 = 3 RATS provide R_{x2} = {15 K, 25 K, 35 K } bps. ==> L_2 = 133.33 s.	$L_H = L_1 + L_2$ = 200 s.	Single Wireless Network in each location contributes R_S = 20 Kbps. ==> L_S (in each location) = 500 s.	Swiftness of data delivery by Heterogeneous Networking System over Single Wireless Network = 800 s.
d)	m_1 = 2 RATS yield R_{x1} = {10 K, 20 K } bps. ==> L_1 = 333.33 s.	m_2 = 2 RATS provide R_{x2} = {30 K, 10 K } bps. ==> L_2 = 250 s.	$L_H = L_1 + L_2$ = 583.33 s.	Single Wireless Network in each location contributes R_S = 20 Kbps. ==> L_S (in each location) = 500 s.	Swiftness of data delivery by Heterogeneous Networking System over Single Wireless Network = 416.67 s.

bandwidth specifically. Right here; x = 1, 2, ⋯, m_y holds good. Consequently, as per the provided bandwidth, x^th RAT in y^th locality is capable of transferring b_{xy} number of bits. That is, $b_{xy} \propto B_{xy}$. Accordingly, x^th chunk of data comprises b_{xy} bits.

Moreover, entire patient's sensed information of N bits is split into 'm_y' chunks (in y^th locality) and each chunk of data is transmitted by one RAT that is there in y^th place. Additionally, consider that x^th RAT in y^th locality can transmit the x^th chunk of data with the data rate of R_{xy} bits per second. (By the same token, $R_{xy} \propto B_{xy} \propto$ x^th chunk of data ; x = 1, 2, ⋯, m_y). Therefore, all of the 'm_y' RATs (that are there in y^th territory) have the overall bit rate of $\sum_{x=1}^{m_y} R_{xy}$ bps. Consequently, it takes $L_y = \frac{N}{\sum_{x=1}^{m_y} R_{xy}}$ seconds time for m_y RATs to send the entire data (from the edge of (y-1)^th territory upto the boundary of y^th area). Thus, it takes $\sum_{y=1}^{M} L_y$ seconds time for the heterogeneous network to transmit the entire N bits data from patients's cell phone to the hospital.

Furthermore, single wireless network allows R_S bits per second. Thus, to transmit N bits of data in y^th territory; it takes $L_S = \frac{N}{R_S}$ seconds time. Hence, heterogeneous network dispatches data much faster than the single wireless network by $(M \times L_S - \sum_{y=1}^{M} L_y)$ seconds.

Moreover, comparison is given below in Table 3 to evaluate the performance of the proposed heterogeneous networking system over the usage of single wireless network [14–18] for transmitting the data from patient's cell phone to the hospital.

Equivalently, Table 3 reveals that heterogeneous networking system disseminates data from the source to destination with the lowest latency when compared to the usage of single wireless network.

Additionally, B_H is the bandwidth used by the entire heterogeneous networking system in all M locations. That is, $B_H = \sum_{y=1}^{M} B_y$. Here, B_y is the bandwidth used in y^th locality and $B_y = \sum_{x=1}^{m_y} B_{xy}$ with B_{xy} representing the bandwidth that can be utilized by x^th RAT that is there in y^th locality. Further, B_S is the bandwidth used by single wireless network in a location. As M locations are there, single wireless network makes use of M × B_S bandwidth. Thus, Spectrum Efficiency of heterogeneous networking system over the single wireless network is taken as: S.E. = $\frac{B_H}{B_H + M \times B_S}$.

Accordingly, from Table 4, it can be noticed that if one RAT does not have enough bandwidth to contribute, then, other RATs that are there in the same locality can provide the sufficient bandwidth. Because of this reason, Spectrum Efficiency becomes more for the heterogeneous networking system when compared to the single wireless network of [14–18].

However, in order to deduce the latency graph in a particular y^th locality; R_{xy} = R, ∀ x is presumed henceforth. Thereafter, the

TABLE 4 Spectral efficiency of the proposed heterogeneous networking system over the usage of single wireless network as in [14–18]. (Here, m_y heterogeneous RATs are there in y^{th} specific territory. However, y = 1, 2, 3 (==> M = 3) locations are assumed to be there in between patient's cell phone and the hospital. In any case, x^{th} heterogeneous RAT in y^{th} explicit region can exploit the best possible channel (or white space); whereas utilizing single wireless network (to transmit the data) can only allocate its available channel alone, which may not be the optimum channel)

S.No.	m_1 number of RATs in first location render $B_1 = \sum_{x=1}^{m_1} B_{x1}$ bandwidth	m_2 number of RATs in second location offer $B_2 = \sum_{x=1}^{m_2} B_{x2}$ bandwidth	m_3 number of RATs in third location contribute $B_3 = \sum_{x=1}^{m_3} B_{x3}$ bandwidth	Utilization of single wireless network in all 3 locations provide $3 \times B_S$ bandwidth.	Spectral Efficiency of the heterogeneous networking system over the usage of single wireless network = S.E. = $\frac{B_1+B_2+B_3}{3\times B_S+B_1+B_2+B_3} \times 100$
a)	$m_1 = 2$ RATS can give $B_1 = 15$ KHz + 20 KHz = 35 KHz	$m_2 = 3$ RATS can give $B_2 = 20$ KHz + 20 KHz + 25 KHz = 65 KHz	$m_3 = 2$ RATS can give $B_3 = 20$ KHz + 15 KHz = 35 KHz	$3 \times B_S = 3 \times 20$ KHz = 60 KHz	S.E. = $\frac{135}{195} \times 100 =$ 69.23
b)	$m_1 = 1$ RAT does not have any free bands. So, RAT utilizes the white space of $B_1 = 1$ MHz bandwidth.	$m_2 = 2$ RATS can give $B_2 = 30$ KHz + 10 KHz = 40 KHz	$m_3 = 3$ RATS can give $B_3 = 15$ KHz + 10 KHz + 20 KHz = 45 KHz	$3 \times B_S = 3 \times 20$ KHz = 60 KHz	S.E. = $\frac{1085}{1145} \times 100 =$ 94.76
c)	$m_1 = 4$ RATS can give $B_1 = 10$ KHz + 15 KHz + 5 KHz + 10 KHz = 40 KHz	$m_2 = 1$ RAT gives $B_2 = 10$ KHz bandwidth.	$m_3 = 2$ RATs can give $B_3 = 10$ KHz + 15 KHz = 25 KHz	$3 \times B_S = 3 \times 20$ KHz = 60 KHz	S.E. = $\frac{75}{135} \times 100 =$ 55.55
d)	$m_1 = 1$ RAT does not have any free bands. So, RAT utilizes the white space of $B_1 = 1$ MHz bandwidth.	$m_2 = 1$ RAT does not have any free bands. So, RAT utilizes the white space of $B_2 = 1$ MHz bandwidth.	$m_3 = 1$ RAT does not have any free bands. So, RAT utilizes the white space of $B_3 = 1$ MHz bandwidth.	$3 \times B_S = 3 \times 20$ KHz = 60 KHz	S.E. = $\frac{3000}{3060} \times 100 =$ 98.04

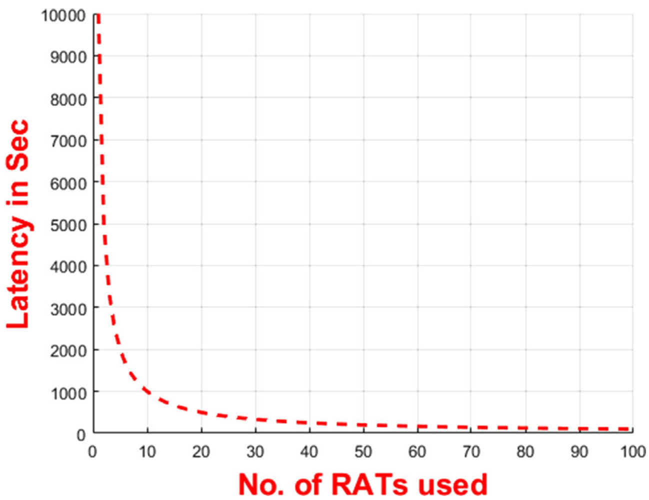

FIGURE 6 Latency for transmissions carried through multiple RATs

resulting latency for the effective usage of 'm_y' heterogeneous RATs in y^{th} territory becomes $L_y = \frac{N}{m_y R}$ s.

In contrast to the preceding heterogeneous network, if a singular wireless network's RAT is exploited in y^{th} territory to transfer the entire data of N bits, then its latency becomes: $\frac{N}{R}$. Consequently, latency of heterogeneous networks gets lowered by a factor of 'm_y' in y^{th} region. The same is unveiled in Figure 6.

To extract the Figure 6; data size of a patient (N) = 10^9 bits and R = 10^5 bps are adopted. Additionally, it is discerned from Figure 6 that availing 'm_y' = 10 RATs, 20 RATs, and 30 RATs incur the latencies of 1000 s (or 16.6667 min) latency, 500 s (or 8.3333 min), and 333.3333 s (or 5.5556 min), respectively. Thus, involving more number of RATs (that are there in y^{th} territory) brings out lower latencies.

Moreover, by utilizing white space channels, 'White Space Spectral efficiency' obtained in the specific y^{th} territory is: $\eta = \frac{\zeta}{\zeta+\xi} \times 100$. Here, ζ specifies the number of white space channels adapted and ξ denotes the number of licensed channels availed by RATs in y^{th} region. Further, $\zeta + \xi$ is considered to be 1000. Then, as ζ increases, η also gets increased, as displayed in Figure 7.

Thus, Figures 6 and 7 indicate that the proposed system reduces latency and also increases 'White Space Spectral efficiency' in a particular territory.

5 | CONCLUSION

In this paper, a real-time remote health monitoring system using heterogeneous multiple RATs has been presented. The proposed system sends the patients' sensed data very swiftly to the doctor by making use of multiple heterogeneous networks. By employing separate control white space channel and SDR concepts, hand-off between adjacent RATs is done with low latency. Additionally, bandwidth is made available always to heterogeneous networks by utilizing white spaces.

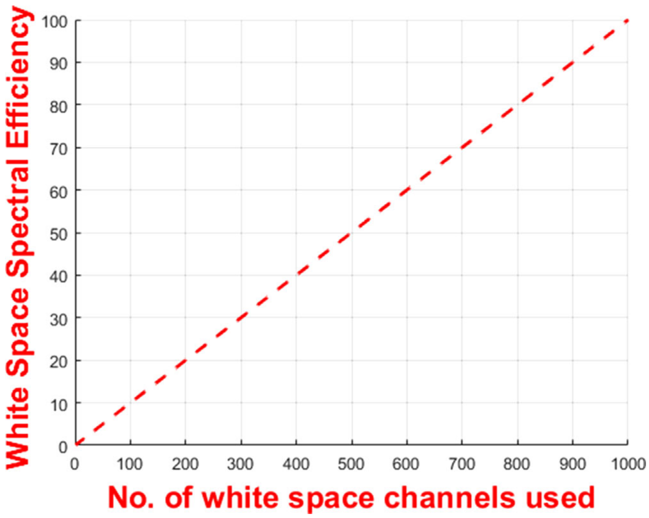

FIGURE 7 Number of White Space channels versus 'White Space Spectral efficiency'

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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How to cite this article: Naidu, K., Sunkaraboina, S.: Remote health monitoring system using heterogeneous networks. Healthc. Technol. Lett. 9, 16–24 (2022). https://doi.org/10.1049/htl2.12020