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Research Article

Wireless Healthcare Monitoring with RFID-Enhanced Video Sensor Networks

Hande Alemdar, Yunus Durmus, and Cem Ersoy

NETLAB, Computer Engineering Department, Bogazici University, 34342 Istanbul, Turkey

Correspondence should be addressed to Hande Alemdar, hande.ozgur@boun.edu.tr

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In pervasive healthcare systems, WSNs provide rich contextual information and alerting mechanisms against odd conditions with continuous monitoring. Furthermore, they minimize the need for caregivers and help the chronically ill and elderly to survive an independent life. In this paper, we propose an outdoor monitoring environment and evaluate the capabilities of video sensor networks for healthcare monitoring in an outdoor setting. The results exhibit that their capabilities are limited. For this reason, we proposed several enhancements for reducing the traffic load on the network for better performance. RFID is a very mature technology that has already been used in many areas. The RFID-enhanced video sensor networks reduce the network traffic load. Moreover, the proximity of the healthcare professionals who are also moving in the surveillance area is also used for better balancing the network load. Finally, for assuring the reporting of the emergency events with low latencies, we propose an emergency frame based queuing mechanism and evaluated its performance through simulations.

1. Introduction

One of the major challenges of the world for the last decades has been the continuous elderly population increase in the developed countries [1]. Hence, the need of delivering quality care to a rapidly growing population of elderly while reducing the healthcare costs is an important issue [2]. Constant monitoring will increase early detection of emergency conditions and diseases for at-risk patients and also provide wide range of healthcare services for people with various degrees of cognitive and physical disabilities [3]. In-home pervasive networks may assist residents and their caregivers by providing continuous medical monitoring, memory enhancement, control of home appliances, medical data access, and emergency communication [4, 5]. While continuous in-house monitoring will pose many benefits on futuristic healthcare monitoring scenarios, there are cases where indoor monitoring is not sufficient. When the elderly who are susceptible to sudden falls or the patients recovering from an operation are considered, the continuous monitoring in indoor places will not be sufficient for surviving an independent life. They should be able to move around freely while being monitored. Wireless sensor networks can be the remedy in that case. With the advances in Complementary Metal Oxide Semiconductor (CMOS) cameras and availability of low-cost hardware have led to the emergence of Video Sensor Networks (VSNs). These camera-equipped sensors are capable of generating and relaying video streams. Generally, VSNs operate in an event-triggered mode. Nodes start producing video frames as soon as they detect a target within the sensing radius and the Field of View (FoV) and continue producing video frames as long as the target is within the range as shown in Figure 1. The number of frames produced is a function of the target residence time inside the coverage area and the camera frame rate. The residence time depends on the target speed, V, and the path length, D_{AB}, covered inside the FoV.

Video surveillance at hospitals, retirement homes and elderly care facilities is widely available today. However, its intended use is limited with security only rather than real-time safety and healthcare monitoring. Moreover, it is generally available for indoor environments where the probability of observing emergency conditions due to mobility

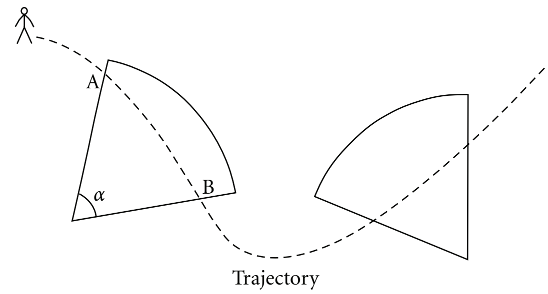


Figure 1: Representation of video sensor nodes' event detection.

of the users is relatively lower and also the probability of being detected by a healthcare professional is higher. Nevertheless, it is very likely in a hospital or elderly care facility setting that users move between different parts of the facility. In Figure 2, a real hospital layout is depicted. The dark grey (green) areas between the buildings of the facility are gardens and also the light grey parts are the walking paths among the buildings. These places are also the high-risk areas for emergency situations such as sudden falls. Since the most scarce resource in healthcare facilities is the healthcare professionals, it is infeasible to monitor the residents all the time by the hospital personnel directly. Instead, we propose using inexpensive, tiny wireless video sensor nodes which are easily deployed and have self-organization capability. Also, they do not impose boundaries for the monitored area and addition of new equipment requires no extra cabling and calibration effort. Since we deploy a large amount of these inexpensive video sensor nodes, they are more robust to failures than fixed cameras that are installed with planning. They do not possess the risk of losing complete coverage when a single node fails. Although having these advantages, there exist some drawbacks with VSNs such as the battery life. The energy consumption is the most problematic aspect of VSNs, and it is directly related to the network lifetime [6]. Hence, there exists significant research effort for rechargeable sensor networks that are aimed to be deployed in habitat monitoring. The VSNs with solar cells will be commercially available for most users [7] in a near future.

One other possible application area of VSNs for healthcare is disaster recovery or military hospital conditions in which no infrastructure is available. Ad hoc deployment of VSNs can be used for increasing the quality of the healthcare service.

In this paper, we study an outdoor healthcare monitoring scenario with VSNs and explore the ways to provide real-time and continuous care to the elderly and chronically ill while keeping the costs for equipment, maintenance, and person relatively lower. This paper is organized as follows: in the following section, we provide some examples of healthcare monitoring applications that already exist. In Section 3, we define the outdoor monitoring scenario with the challenges observed and the proposed solutions to these challenges. We present our results in Section 4. Finally, Section 5 concludes the paper.

2. Healthcare Monitoring Applications

Although there are several prototype and commercial applications for indoor healthcare monitoring for the elderly, children, and chronically ill people, there are only a few proposals for outdoor healthcare monitoring. When indoor healthcare applications are explored, it is observed that the main focus categories include activities of daily living monitoring, location tracking, medication intake monitoring, medical status monitoring, and fall and movement detection. In the first category, the applications try to identify and differentiate the everyday activities of the patients and the elderly, such as watching television, sleeping, and ironing, and be able to detect odd conditions [8, 9]. Location tracking, the medication intake reminder, and monitoring systems can help cognitively impaired people to survive independently [10–12]. Medical care applications make use of biosensors and environmental sensors in order to obtain comprehensive health status information of the patients, including ECG, heart rate, blood pressure, skin temperature, and oxygen saturation [13]. Fall and movement detection applications are focused on the physiological conditions such as posture and fall detection for people that need special care like the elderly people who are susceptible to sudden falls which may lead to death, infants, or patients recovering from an operation [14, 15].

There are some outdoor monitoring applications. Martí et al. proposes Mobile Agent Electronic Triage Tag System (MAETTS) [16]. The system is based on mobile agents which are carried by the healthcare personnel. The mobile agents are used in emergency conditions, and they act like intermediate nodes in an ad hoc network. The healthcare person initiates the communication when a patient is identified. The identification of the patients are accomplished with the use of RFID tags, and GPS is used to locate the emergency situation. The system relies on the mobile handheld devices carried by the healthcare professionals and does not require any infrastructure.

CodeBlue [17] is based on a publish-and-subscribe routing framework, and its main aim is to provide coordination and communication among wireless medical devices in an ad hoc manner. It also integrates an RF-based localization system used for locating the patients and healthcare professionals [18]. The healthcare professionals also carry mobile devices like PDAs and laptop computers for accessing vital signs of the patients real time.

The LifeGuard [19] is another project which offers health information monitoring. The system includes ECG, respiration, pulse oximeter, blood pressure, accelerometer, and skin temperature sensors which are bundled into a specific device carried by the patients. The data collected from the sensors also stored on the device until a Bluetooth-capable tablet computer is found by the system to act like a base station. The data can be transferred to the computer for further evaluation.

All of the previous works mentioned require patients to carry a number of mobile devices and sensors that are very inefficient for elderly and chronically ill. Video surveillance sensor networks can be useful in such cases. Although their

Figure 2: The layout of Cerrahpasa Hospital of Istanbul University.

capabilities are limited at the moment, they have great potential and their performance can be improved with the help of tiny RFID tags as proposed in this paper.

3. Healthcare Monitoring with RFID-Enhanced VSNs

One of the biggest challenges of VSNs is the increased traffic volume. This situation poses significant challenges for the successful arrival of the video frames at the sink. During wireless communication, environmental noise and channel characteristics lead to packet errors frequently. In critical applications such as healthcare monitoring, these challenges must be addressed carefully. The successful arrival of most of the frames and within a tolerable amount of latency are the main issues for such applications. VSNs for healthcare monitoring are intended to track and monitor only the targeted patients or residents within the surveillance area. Therefore, the traffic caused by other people, animals or objects moving in the same area should be suppressed. We propose the use of small inexpensive RFID tags for this purpose. This is accomplished via enhancing the triggering mechanism of video sensor nodes with RFID readers as in the case of SkyeRead M1-Mini [20] which is a low-profile RFID device that reads and writes industry standard 13.56 MHz RFID tags. This RFID reader can also be connected to Crossbow's MICA2DOT mote [21]. With the use of similar technology, VSNs can be improved so that they produce frames only for the intended targets. This mechanism can also be used for privacy purposes. The patients who are not willing to be monitored by the video cameras can also be identified by RFID tags, and video sensor nodes will not be activated for those users. An example scenario is depicted in Figure 3.

In our outdoor monitoring application, an active RFID system operating in the Ultra-High-Frequency (UHF) range provides the necessary function, since it allows querying the tags from longer ranges than other lower frequencies. Additionally, RFID and sensor hardware convergence, which has already been realized in end products [22, 23], enables the use of RFID-enabled sensors. When VSNs are improved with these additional sensing mechanisms, not only video frames but also physiological information will be of much importance. Furthermore, with the help of extra sensors, the emergency situations such as high blood pressure or high body temperature can be sensed and reported together with the video frames as in the case of indoor monitoring. These frames also contain life-critical information; therefore, we propose an emergency-based queueing mechanism for the emergency video frames in multihop VSNs. With this feature, the video frames that contain an emergency situation identifier are given priority over those that are not emergent. The video frames containing healthcare information help identifying the situation better and taking the required actions quickly.

In this study, we explore the applicability of VSNs through simulations for an outdoor healthcare monitoring scenario. We also propose the use of RFID tags for efficient bandwidth usage and improvements in packet loss and latency. Because once we achieve an acceptable level of monitoring, we can afford more patients to be taken care of

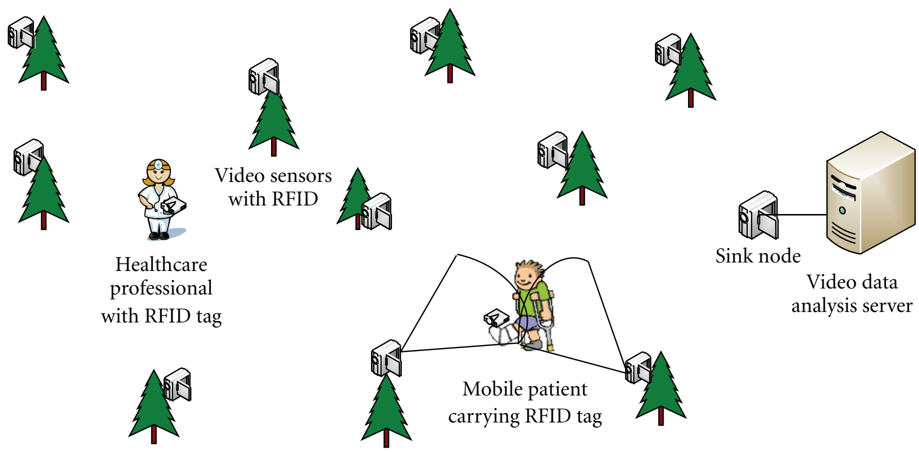


Figure 3: Application scenario with RFID-enhanced video sensors deployed in a healthcare facility garden.

with a reduced number of healthcare professionals. In this way, not only patients will receive a higher quality healthcare service but also the healthcare professionals will spend their times more efficiently.

4. Simulation Results

We use the OPNET simulation environment in the performance evaluation. In order to have a realistic WSN setting, SMAC [24] and GPSR [25] protocols are used as the underlying MAC and routing protocols, respectively. Since OPNET does not have SMAC and GPSR as built-in functions, we have developed the models for SMAC and GPSR using the OPNET development environment. The sink is placed at the middle of one side of the surveillance area where the sensor nodes are deployed uniformly in a random fashion. All the nodes are capable of taking images and compressing them with the cameras integrated on their hardware. Because of the limited processing capability of the commercially available sensor-mounted cameras, efficient compression techniques cannot be achieved [26]. Since the size of the data transmitted is directly related to the size of the image, SQCIF (128×96 pixel size) format is assumed. The image module employs intraframe encoding which results in compressed images of size 10 kbits. Reduced image size is accomplished by the JPEG compression which is assumed to be available on the image module.

Sensor nodes are designed to dynamically power up and down the equipments to save energy. Especially, the antenna part of the devices changes its power state in duty cycles (DC). Sensor nodes are expected to agree upon the duty cycle strategy and keep on networking without large amounts of information losses. We use 10% DC in our simulations, since carrying video traffic requires larger amount of work when compared to scalar values. However, since we want to keep lower the energy expenditure, we do not prefer to use higher values. The buffer size at the sensor nodes is selected to be 200 kbits. For video traffic, the late packet is a lost packet, therefore, we only keep 20 frames in sensor buffers, and the excess amount of the frames are dropped immediately.

Table 1: Simulation parameters.

Parameter	Value
Surveillance area	200×100 m
Number of sensors	40 nodes
Deployment type	Uniform random
Video frame size	10 kbits
Packet size	1 kbits
Buffer size	200 kbits
Camera detection range	30 m
Communication range	40 m
Field of view	52 degrees
Patient mobility model	Random waypoint
Duty cycle	10%
Speed of the patients	1 m/s
Routing	GPSR
MAC	SMAC

The software-controlled frame rate feature allows capturing the video with rates 1 to 8 frames per second (fps). Event-triggered data generation is simulated where the triggering event is the visual detection of a patient. Since the cameras support background subtraction feature, they only produce an image when the certain amount of pixels alters. Hence, triggering occurs when the patient is within the camera detection range of 30 m and is within the Field of View (FoV) of 52 degrees. The patient is assumed to move in the surveillance area according to the random waypoint mobility model, where the patient speed is 1 m/s and the pause time is set to zero seconds. The simulation parameters are summarized in Table 1.

Experiments are designed for exploring the effects of the bandwidth, camera frame rate, and the number of the patients. The investigated factor values are provided in Table 2. Each simulation is repeated five times. In order to assess the effects of the factors, collected performance metrics are the percentage of the received frames at the sink per second and the average frame latency in seconds.

Table 2: Investigated factors.

Factor	Values
Bandwidth	250 kbps, 500 kbps, 750 kbps, 1 Mbps
Camera frame rate	1, 2, 4, 8 fps
Number of the patients	10, 20, 30, 40

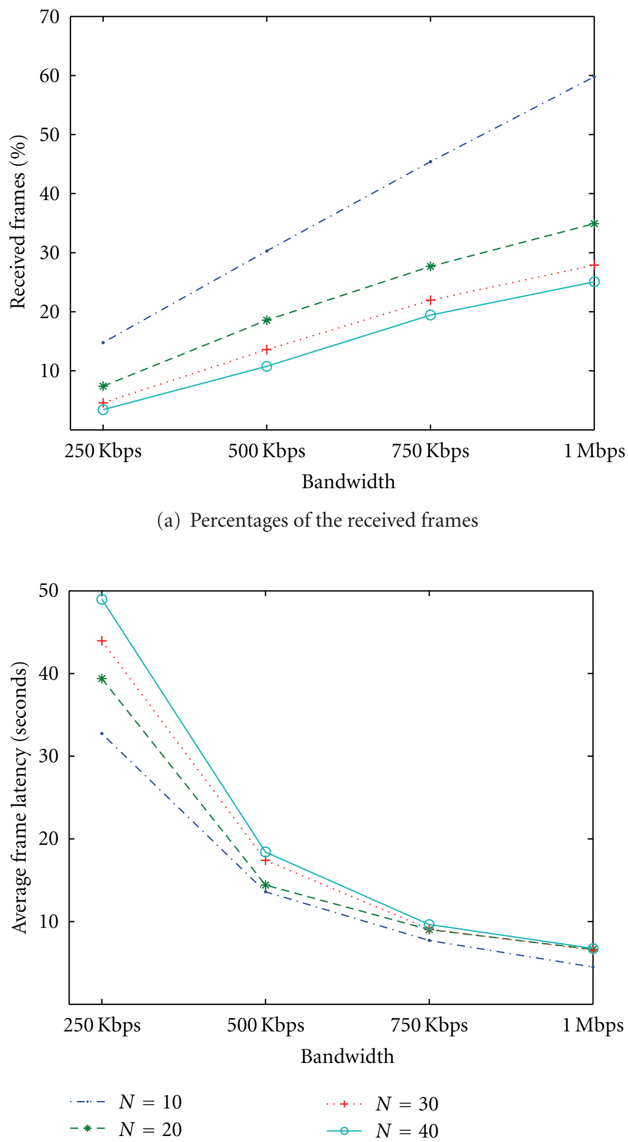
Simulation results presented in Figure 4 indicate that with a 250 kbps bandwidth, the percentage of the received frames is below 10% when the number of the patients exceeds 10. We can conclude that for receiving a reasonable amount of the frames at the sink, we need higher bandwidths. The percentage of the received frames with 10 patients in the surveillance area shows a linear increase while for 20, 30, and 40 patients; the increase in the received frames is not as high as in the 10-patient case. Hence, only a small number of patients can be monitored by the VSN properly. However, it is unlikely that a nursing home or hospital will have less than 10 patients wandering around. Therefore, further improvements are required other than higher bandwidths for such a scenario. As far as the latency of the frames are considered, which is also crucial in healthcare monitoring, again, we encounter poor performance at lower bandwidths. The 250 kbps bandwidth can only provide latencies above 30 seconds and up to 50 seconds for 40 patients although the successful frame arrival rates are very low. The average frame latency falls below 20 seconds with 500 kbps, 750 kbps, and 1 Mbps bandwidths provide nearly 10 seconds of frame latency with four frames per second rate as shown in Figure 4(b).

With lower camera frame rates such as two fps, we obtain better results both in terms of the percentage of the received frames and the average latency as represented in Figures 5(a) and 5(b), respectively. The halved camera frame rate with higher bandwidths like 750 kbps and 1 Mbps provides nearly real-time monitoring for 10 patients, with above 90% frame arrival rate and below one second average latency, at the cost of reduced video quality. The increased number of the patients yields approximately 40% of successful frame arrival with around five seconds of average frame latency.

When we explore the dropped frames in detail, we observe that most of the frames are dropped at the source in lower bandwidths as depicted in Figure 6. With 250 kbps bandwidth, more than half of the camera frames are dropped at the node where they are generated. This implies that either we must have larger buffers at the sensor nodes or larger bandwidths. The larger buffers will not lead to decrease in the latencies; therefore, obtaining larger bandwidths are essential. Semiconductor manufacturers have begun producing transceivers that support data rates up to 1 Mbps [27]. Hence, the next generation wireless sensors will be much more suitable for VSN healthcare applications.

4.1. Effect of RFID Usage. Since the abundance of the patients degrades the performance of the network significantly especially at high camera frame rates, an RFID-triggered sensing mechanism is proposed and tested. This is accomplished via enhancing the triggering mechanism of video sensor nodes with RFID readers. There are low-profile RFID devices like SkyeRead M1-Mini [20] which can also be plugged to Crossbow's MICA2DOT mote [21]. By employing similar technology in VSNs, the traffic initiation is manipulated to produce frames only for the intended patients. The identifying capability of RFIDs can also serve for privacy purposes. The patients who do not prefer to be monitored by the video cameras can also be identified by RFID tags and video frames for these patients are not produced.

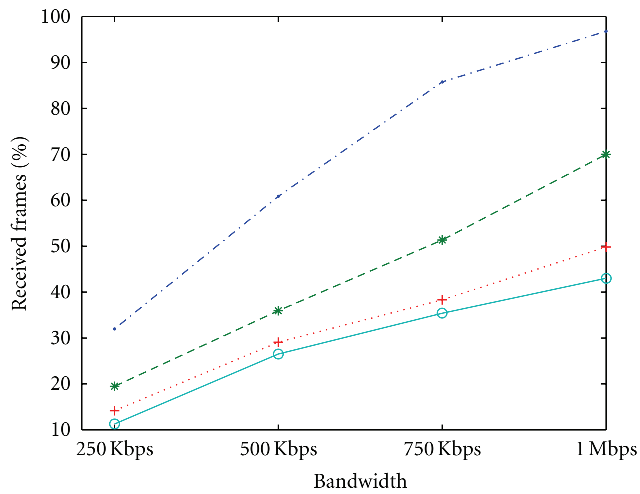
In the RFID-enhanced scenario, the sensor nodes only produce frames when they identify the presence of the intended patients, who are wearing RFID tags. In this way, the extra traffic load arising from other people such



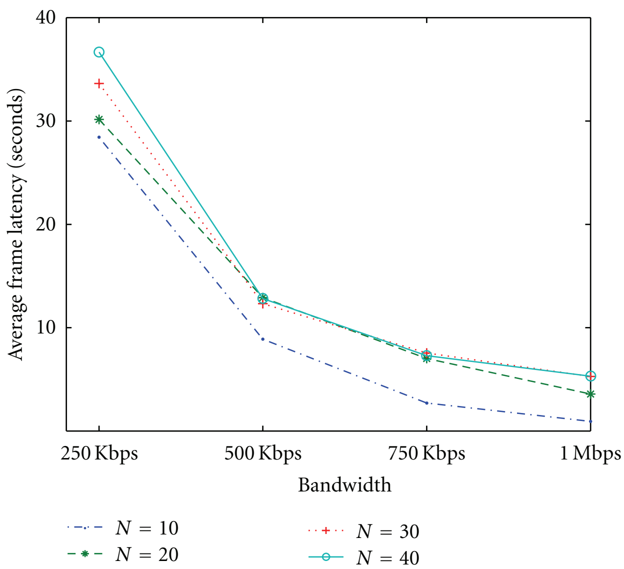
(a) Percentages of the received frames

(b) Average frame latency

Figure 4: Simulation results with four fps camera frame rate.



(a) Percentages of the received frames



(b) Average frame latency

Figure 5: Simulation results with two fps camera frame rate.

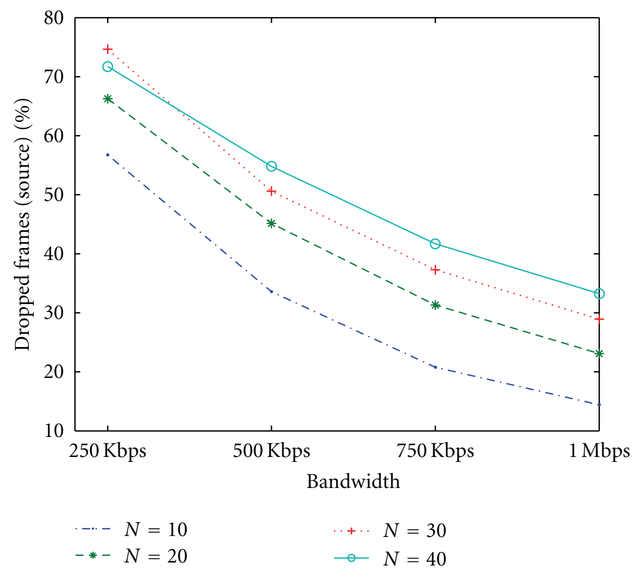


Figure 6: The percentages of the dropped frames at the source with four fps camera frame rate.

Table 3: The reduction in the number of created frames with 8 fps camera frame rate and 1 Mbps bandwidth.

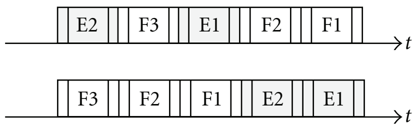
		Number of patients		
		10	**20**	**30**
No. of pedestrians	**40**	66.4%	36.0%	14.6%
	30	60.6%	25.0%	
	20	47.5%		

Table 4: Latency reduction with 1 Mbps bandwidth and 8 fps camera frame rate.

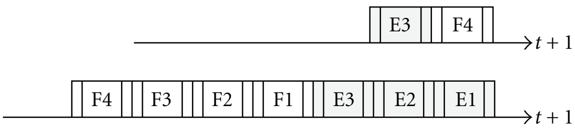
		Number of patients		
		10	**20**	**30**
No. of pedestrians	**40**	32.4%	17.4%	7.2%
	30	27.1%	10.9%	
	20	18.1%		

as healthcare professionals or caregivers, relatives of the patients, gardeners, and security guards, who are also moving around, will not affect the network performance. In Table 3, we demonstrate the created frame reduction percentages for different proportions of decrease in the number of the patients. According to the simulation results that are mentioned in Section 4, the created frames are reduced to 66.4% with a 75% decrease in the number of the patients. If only 25% of the 40 patients were wearing RFID tags which identify them as critically ill people who need closer monitoring with the VSNs, the created video frames will be reduced 66.4%. With 1 Mbps bandwidth, the effect on the latencies are given in Table 4. The reduction in the average frame latency with a decrease in the number of the patients with the use of RFID tags can go up to nearly 30%.

Besides providing performance increase by focusing only on the intended patients, the WSN and RFID integration that has already been realized in end products will also be used for sensing purposes. These products will be widely used in the next-generation WSNs. The concurrent use of the RFID and VSNs also moves us one step further in identifying the context of the sensed events. While monitoring with small video sensor nodes, the patient's posture and pose can be estimated with local image processing on the video sensor node. With this feature, we can identify some odd conditions like *patient has fallen down* or *patient is walking awkwardly*. However, the physiological emergency situations like *patient's body temperature goes up* or *patient is sweating too much* cannot be identified by image processing. The integrated RFID-WSN sensing technology will be the



(a) Queuing at the sensor node at time t.



(b) Queuing at the sensor node at time $t + 1$.

FIGURE 7: Emergency frame-based queuing.

solution for these more complex tasks. In such a scenario, VSNs will have to carry emergency information as well. In the following section, we propose a new technique for handling the emergency situations in VSNs.

4.2. Emergency Frame Based Queuing. The concurrent use of RFID, VSNs, and image processing facilitates identifying the emergency situations such as high blood pressure, high body temperature, and sudden falls. These relatively small yet life-critical data can be integrated in large video frames or can be sent alone as separate frames, making these frames the *emergency frames*. The emergency video frames containing healthcare information help identifying the situation better and taking the required actions quickly. Since these frames contain critical information, they must be assured to arrive at the sink. For this purpose, we propose an Emergency Frame Based Queuing (EFBQ) mechanism to improve the delivery of the emergency video frames in multihop VSNs. With this feature, the video frames that contain the emergency situation identifier are given priority over those that are not emergent.

In Figure 7(a), the frames arriving at a node at a given time t is represented. There are five frames two of which are the emergency frames namely, E1 and E2. Other frames F1, F2, and F3 are nonemergent video frames. Without EFBQ, these frames would be relayed in a First Come First Serve (FCFS) manner. Yet, with EFBQ, the relaying order of these frames are altered according to their emergency flags and the time of arrivals as depicted. Suppose that before relaying any of these frames, two new frames one of which is the emergency frame arrived at the node as shown in Figure 7(b). The new order of the relaying queue at time $t + 1$ is also presented. In this way, at any given time the emergency frames are given priority over nonemergent ones for assuring low latencies and higher arrival rates.

During the experiments, a random emergency frame generation with a probability of 10% is implemented in order to emulate the real-life medical emergencies. Therefore, 10% of the generated frames are randomly selected to be emergent frames. According to the new queueing mechanism, the emergency frame arrival rates are shown to be increased as depicted in Figure 8. For eight fps camera frame rate

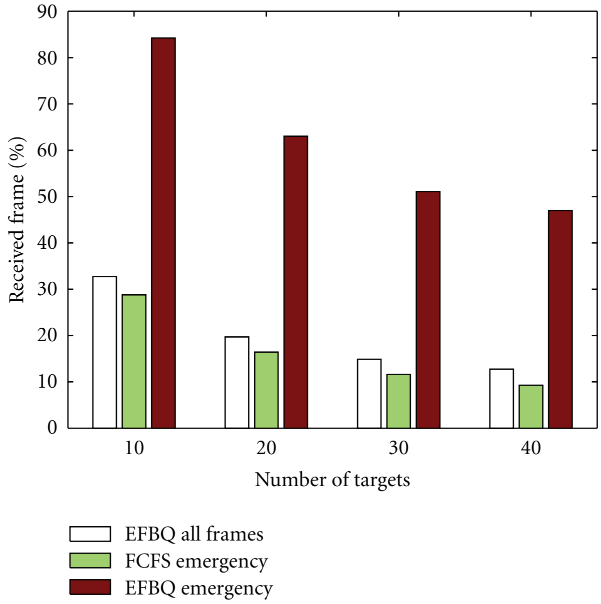


FIGURE 8: The percentages of the received frames at the source 1 Mbps with 8 fps camera frame rate.

with 1 Mbps bandwidth, the received frame percentage of all frames for 10 patients is a little above 30% with the EFBQ. With the FCFS queueing, since the emergency frames are treated as any other frames, the percentage of the received frames are a little below 30%. However, the emergency frame delivery ratio becomes nearly 85% with EFBQ. Again, with the increased number of the patients, EFBQ enables us to deliver five times higher number of emergency frames to be delivered successfully.

4.3. Effect of the Proximity of Healthcare Professionals. Several experiments are conducted on the capabilities of the VSNs for healthcare monitoring. The results exhibit that VSN node's capabilities are limited. Therefore, reducing the number of the frames carried by the network will help improving the performance of the VSN. For this reason, it is reasonable to accept that if a patient has already a healthcare professional nearby, he/she will not need additional attention from the VSN system. This observation can be incorporated for further reducing the number of created frames in the system. Here, it is important to note that since we use RFID for identifying the patients and the healthcare professionals, we can easily define some critical patients who are needed to be monitored under all conditions. Such kind of exceptions can easily be integrated into the monitoring system with a simple lookup. However, for the majority of the patients this may not be the case. We also assume that there are several healthcare professionals on the surveillance area who are again identified by the system with the use of RFID tags. When a patient is already near a healthcare professional, then the VSN does not produce any frames for that patient as long as the patient is within the attention range of that healthcare personnel.

The healthcare professional is able to take care for a uniformly randomly located patient when the distance between them is below a threshold value which is called the *attention distance*. Given N healthcare professionals randomly distributed over a rectangular field, the probability of a patient is within the attention range of at least one healthcare professional can be formulated as the distance d between two random points, which are the position of the patient and the position of the healthcare professional. We assume that the length and the width of the field are D_1 and D_2, respectively, with $D_1 \leq D_2$. The cumulative distribution and the probability density functions of the random variable d are provided in (1) and (2), respectively, [28], where $\beta = D_1/D_2 \leq 1$ is the shape parameter and $\alpha = d/D_1$

$$F(d) = \begin{cases} 0, & \alpha < 0, \\ \beta\alpha^2\left[\dfrac{\beta\alpha^2}{2} - \dfrac{4}{3}\alpha(1+\beta) + \pi\right], & 0 \leq \alpha < 1, \\ \dfrac{2}{3}\beta\sqrt{\alpha^2-1}(2\alpha^2+1) \\ \quad -\dfrac{1}{6}\beta(8\alpha^3 + 6\beta\alpha^3 - \beta) \\ \quad +2\beta\alpha^3\sin^{-1}\left(\dfrac{1}{\alpha}\right), & 1 \leq \alpha < \beta^{-1}, \\ \dfrac{2}{3}\beta\sqrt{\alpha^2-1}(2\alpha^2+1) \\ \quad -\dfrac{1}{2}\beta^2\left(\alpha^4 + 2\alpha^2 - \dfrac{1}{3}\right) \\ \quad +\dfrac{2}{3}\sqrt{\alpha^2-\beta^{-2}}(2\beta^2\alpha^3+1) \\ \quad +\dfrac{1}{6}\beta^{-2} - \alpha^2 \\ \quad +2\beta\alpha^2\sin^{-1}\dfrac{1}{\alpha} \\ \quad -2\beta\alpha^2\cos^{-1}\dfrac{1}{\beta\alpha}, & \beta^{-1} \leq \alpha < \sqrt{1+\beta^{-2}}, \\ 1, & \sqrt{1+\beta^{-2}} \leq \alpha, \end{cases} \tag{1}$$

$$f(d) = \frac{1}{D_1}\begin{cases} 2\beta^2\alpha^3 + 2\beta\alpha\pi \\ \quad -4\beta\alpha^2(1+\beta), & 0 \leq \alpha < 1, \\ 4\beta\alpha\sqrt{\alpha^2-1} \\ \quad -2\beta\alpha(2\alpha+\beta) \\ \quad +4\beta\alpha\sin^{-1}\left(\dfrac{1}{\alpha}\right), & 1 \leq \alpha < \beta^{-1}, \\ 4\beta\alpha\sqrt{\alpha^2-1} \\ \quad +4\beta^2\alpha\sqrt{\alpha^2-\beta^{-2}} \\ \quad -2\alpha(\beta^2\alpha^2+1+\beta^2) \\ \quad +4\beta\alpha\sin^{-1}\left(\dfrac{1}{\alpha}\right) \\ \quad -4\beta\alpha\cos^{-1}\left(\dfrac{1}{\beta\alpha}\right), & \beta^{-1} \leq \alpha < \sqrt{1+\beta^{-2}}, \\ 0, & \text{otherwise}. \end{cases} \tag{2}$$

With a binary detection approach $p(x)$, the attention probability of a healthcare professional, can be formulated as in (3), where d_t is the attention distance and $x \geq 0$ is the distance between the healthcare professional and the patient

$$p(x) = \begin{cases} 1, & x \leq d_t, \\ 0, & x > d_t. \end{cases} \tag{3}$$

Therefore, the probability of a healthcare professional having a patient in his attention circle becomes

$$P(A) = \int_0^\infty p(x)f(x)dx = \int_0^{d_t} f(x)dx = F(d_t). \tag{4}$$

Since there are N healthcare professionals, the probability of a patient being monitored by k out of N healthcare professionals is a binomial distribution

$$p(N,k) = \binom{N}{k} F(d_t)^k [1-F(d_t)]^{N-k}. \tag{5}$$

Equation (5) can be approximated by the normal distribution with $\mu = NF(d_t)$ and $\sigma^2 = NF(d_t)[1-F(d_t)]$. Therefore, the probability that a patient will be in at least one healthcare professional's attention circle becomes

$$P(A) = 1 - p(N,0) = 1 - [1-F(d_t)]^N. \tag{6}$$

The attention probability for different number of healthcare professionals and for different attention distances are depicted in Figure 9. With an attention distance of five meters, even 20 healthcare professionals give 0.1 probability of having at least one patient in the attention area. For obtaining higher attention probabilities with 10 healthcare professionals, the attention distance must be at least 20 meters. When we increase the number of the healthcare professionals with a five meters of attention distance, the probability of attention does not improve significantly.

In Figure 10, the effect of the number of healthcare professionals on the attention probability for different attention distances is shown. Ten healthcare professionals with a 15-meter attention distance provide nearly 0.28 probability of attention, meaning that if there are already 10 healthcare professionals in the surveillance area, each of who is able to monitor any patient in 15-meter range, each patient will be monitored by at least one of them with a probability of 0.28. Hence, the number of created frames for that patient will be reduced by 28%.

We simulated the effect of the attention distance of the healthcare personnel with 40 patients, 10 healthcare professionals and for different camera frame rates. The results that are tabulated in Table 5 are matching with the analytical results. In the first column, the created frames per second without any healthcare professionals are given for different frame rates. In the following columns, the created frames per second for 5, 10, and 15 meters of attention ranges of 10 healthcare professionals are provided for different camera frame rates. With all frame rates from 1 to 8 fps, the created frames per second is reduced by approximately

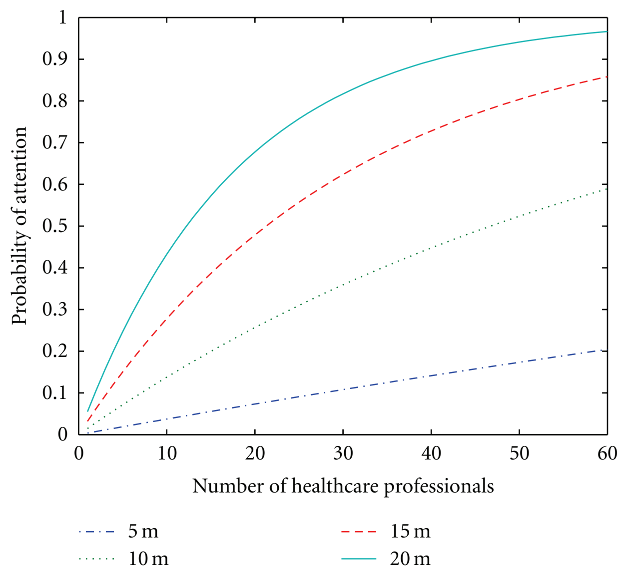


FIGURE 9: The effect of the attention distance on the attention probability with $D_1 = 100$ and $D_2 = 200$.

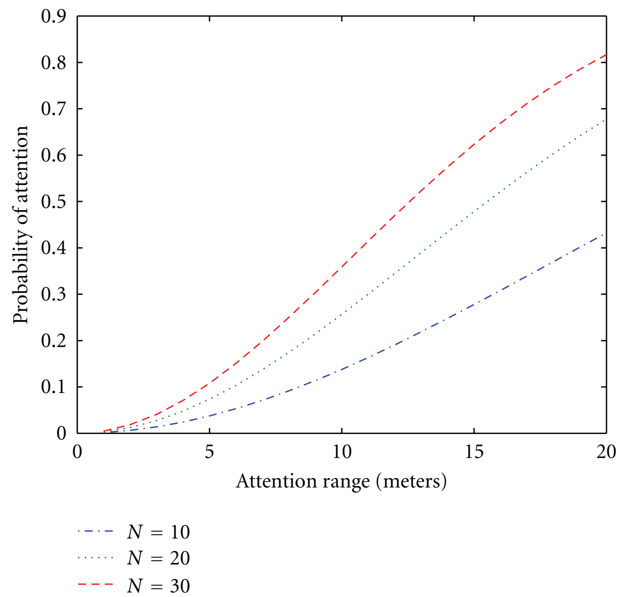


FIGURE 10: The effect of the number of healthcare professionals on attention probability with $D_1 = 100$ and $D_2 = 200$.

TABLE 5: Created frames per second with different camera frame rates and different attention distance ranges.

		0 m	5 m	10 m	15 m
Frame rate	1 fps	16.59	16.42	14.64	11.83
	2 fps	33.17	32.84	29.28	23.66
	4 fps	66.73	67.95	58.56	47.32
	8 fps	138.13	135.89	121.26	97.64

28% with the 15 meters attention distance. Likewise, with 10-meter attention range, the reduction is approximately 12% as indicated by both analytical and simulated results.

The results suggest that there are two factors affecting the attention probability of a patient given a constant number of available healthcare professionals. One is the shape parameter $\beta = D_1/D_2$ which is 0.5 in our case, and the other one is $\alpha = d/D_1$, the attention distance to the length of the surveillance area's shorter side ratio. This means that for different geographical areas that are having equal area sizes, we may obtain different results due to different β and α values.

5. Conclusions

In this paper, we performed a set of simulations for evaluating the performance of VSNs for an outdoor health-care monitoring scenario. The increased traffic volume in VSNs pose significant challenges for successful arrival of the video frames at the sink. Hence, high bandwidths are needed. VSNs for healthcare monitoring are intended to track and monitor only the targeted pedestrians within the surveillance area. Therefore, the traffic caused by other people, animals, or objects moving in the same area should be suppressed. We propose the use of small inexpensive RFID tags for this purpose so that VSNs produce frames only for the intended targets. Moreover, when VSNs are improved with these additional sensing mechanisms, not only video frames but also physiological information will be of much importance. Furthermore, with the help of extra sensors, the emergency situations such as high blood pressure or high body temperature can be sensed and reported together with the video frames as in the case of indoor monitoring. These frames also contain life-critical information; therefore, we propose an emergency-based queueing mechanism for the emergency frames in multihop VSN. With this feature, the video frames that contain emergency situation identifier are given priority over those that are not urgent. The video frames containing healthcare information help identifying the situation better and taking the required actions quickly. The results showed that the EFBQ mechanism significantly improved the delivery ratio of the emergency frames even under heavy traffic load. We also investigated the effect of the proximity of the healthcare professionals to the patients analytically. After that, we conducted simulations and showed that the results were compatible with the analytical solution. The proximity of the healthcare professionals who are already available in the hospital garden is used as a frame reduction mechanism.

In the future, we plan to extend this study with real deployment experiments. In collaboration with a health-care service provider located in Istanbul, we will conduct experiments in their healthcare facility. The experiments will explore the performance of video sensor monitoring along with tracking vital signs of critical patients.

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References

[1] K. Kinsella and D. R. Phillips, “Global aging: the challenge of success,” *Population Bulletin*, vol. 60, no. 1, pp. 3–40, 2005.

[2] J. A. Stankovic, Q. Cao, and T. Doan, “Wireless sensor networks for in home healthcare: potential and challenges,” in *Proceedings of the High Confidence Medical Device Software and Systems Workshop (HCMDSS ’05)*, 2005.

[3] G. Virone, A. Wood, L. Selavo et al., “An assisted living oriented information system based on a residential wireless sensor network,” in *Proceedings of the 1st Transdisciplinary Conference on Distributed Diagnosis and Home Healthcare (D2H2 ’06)*, vol. 2006, pp. 95–100, 2006.

[4] V. Stanford, “Using pervasive computing to deliver elder care,” *IEEE Pervasive Computing*, vol. 1, no. 1, pp. 10–13, 2002.

[5] T. Mcfadden and J. Indulska, “Context-aware environments for independent living,” in *Proceedings of the 3rd National Conference of Emerging Researchers in Ageing*, pp. 1–6, 2004.

[6] J. Zou, C. Tan, R. Zhang, and H. Xiong, “Modeling and optimization of network lifetime in wireless video sensor networks,” in *IEEE International Conference on Communications (ICC ’10)*, pp. 1–6, 2010.

[7] K. Fan, Z. Zheng, and P. Sinha, “Steady and fair rate allocation for rechargeable sensors in perpetual sensor networks,” in *Proceedings of the 6th ACM Conference on Embedded Network Sensor Systems (SenSys ’08)*, pp. 239–252, Raleigh, NC, USA, 2008.

[8] M. Stikic, T. Huynh, K. V. Laerhoven, and B. Schiele, “ADL recognition based on the combination of RFID and accelerometer sensing,” in *Proceedings of the 2nd International Conference on Pervasive Computing Technologies for Healthcare (PervasiveHealth ’08)*, pp. 258–263, 2008.

[9] M. Sung, C. Marci, and A. Pentland, “Wearable feedback systems for rehabilitation,” *Journal of Neuroengineering and Rehabilitation*, vol. 2, article no. 17, 2005.

[10] Y. Chang, C. Chen, L. Chou, and T. Wang, “A novel indoor way finding system based on passive rfid for individuals with cognitive impairments,” in *Proceedings of the 2nd International Conference on Pervasive Computing Technologies for Healthcare*, pp. 108–111, 2008.

[11] M. Lopez-Nores, J. J. Pazos-Arias, J. Garcia-Duque, and Y. Blanco-Fernandez, “Monitoring medicine intake in the networked home: the icabinet solution,” in *Proceedings of the 2nd International Conference on Pervasive Computing Technologies for Healthcare*, pp. 116–117, Tampere, Finland, 2008.

[12] L. Ho, M. Moh, Z. Walker, T. Hamada, and C. -F. Su, “A prototype on RFID and sensor networks for elder healthcare: progress report,” in *Proceedings of ACM SIGCOMM Workshop on Experimental Approaches to Wireless Network Design and Analysis*, pp. 70–75, 2005.

[13] H. Kailanto, E. Hyvärinen, J. Hyttinen, and Ragnar Granit Institute, “Mobile ecg measurement and analysis system using mobile phone as the base station,” in *Proceedings of the 2nd International Conference on Pervasive Computing Technologies for Healthcare*, 2008.

[14] R. Takeda, S. Tadano, M. Todoh, M. Morikawa, M. Nakayasu, and S. Yoshinari, “Gait analysis using gravitational acceleration measured by wearable sensors,” *Journal of Biomechanics*, vol. 42, no. 3, pp. 223–233, 2009.

[15] T. R. Hansen, J. M. Eklund, J. Sprinkle, R. Bajcsy, and S. Sastry, “Using smart sensors and a camera phone to detect and verify the fall of elderly persons,” in *Proceedings of the European Medicine, Biology and Engineering Conference*, 2005.

[16] R. Martí, S. Robles, A. Martín-Campillo, and J. Cucurull, “Providing early resource allocation during emergencies: the mobile triage tag,” *Journal of Network and Computer Applications*, vol. 32, no. 6, pp. 1167–1182, 2009.

[17] V. Shnayder, B. Chen, K. Lorincz, T. R. F. Fulford-Jones, and M. Welsh, “Sensor networks for medical care,” in *Proceedings of the 3rd International Conference on Embedded Networked Sensor Systems*, 2005.

[18] K. Lorincz and M. Welsh, “MoteTrack: a robust, decentralized approach to RF-based location tracking,” in *Proceedings of the 1st International Workshop on Location- and Context-Awareness (LoCA ’05)*, Lecture Notes in Computer Science, pp. 63–82, May 2005.

[19] K. Montgomery, C. Mundt, G. Thonier et al., “Lifeguard—a personal physiological monitor for extreme environments,” in *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology*, vol. 26, pp. 2192–2195, 2004.

[20] SkyeTek. Skyetek m1-mini, 2010.

[21] Crossbow. Mica2dot wireless microsensor mote, 2010.

[22] D. Pardo, A. Vaz, S. Gil et al., “Design criteria for full passive long range uhf RFID sensor for human body temperature monitoring,” in *Proceedings of the IEEE International Conference on RFID*, pp. 141–148, 2007.

[23] A. P. Sample, D. J. Yeager, P. S. Powledge, and J. R. Smith, “Design of a passively-powered, programmable sensing platform for UHF RFID systems,” in *Proceedings of the IEEE International Conference on RFID*, pp. 149–156, 2007.

[24] W. Ye, J. Heidemann, and D. Estrin, “Medium access control with coordinated adaptive sleeping for wireless sensor networks,” *IEEE/ACM Transactions on Networking*, vol. 12, no. 3, pp. 493–506, 2004.

[25] B. Karp and H. T. Kung, “GPSR: Greedy Perimeter Stateless Routing for wireless networks,” in *Proceedings of the 6th Annual International Conference on Mobile Computing and Networking (MOBICOM ’00)*, pp. 243–254, August 2000.

[26] S. Pudlewski and T. Melodia, “On the performance of compressive video streaming for wireless multimedia sensor networks,” in *Proceedings of the IEEE International Conference on Communications (ICC ’10)*, pp. 1–5, Cape Town, South Africa, 2010.

[27] NORDIC-Semiconductors. nrf2401a transceiver, 2009.

[28] L. E. Miller, “Distribution of link distances in a wireless network,” *Journal of Research of the National Institute of Standards and Technology*, vol. 106, no. 2, pp. 401–412, 2001.