

Proposal of Real-Time Echocardiogram Transmission Based on Visualization Modes with WiMAX Access

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Abstract

This study presents a new approach to improve the echocardiogram transmissions over WiMAX networks. Using a compression method based on visualization modes and a reliable method that adapts to the channel conditions, overall performance results are improved compared to classical approaches. The echocardiogram transmission using a compression method based on visualization modes requires lower bandwidth than without considering visualization modes. Furthermore, if the proposed reliability method is also used, the echocardiogram is more often visualized with adequate clinical quality than compressing the echocardiogram without distinguishing the visualization modes and without using a reliability method for the available dataset. The reduction in the bandwidth ranges from 29 kbps to 166 kbps for the simulated scenarios.

1. Introduction

Echocardiograms are widely used to obtain a precise diagnosis of cardiopathies. An echocardiogram is based on the continuous acquisition of ultrasound images of the heart. It has several advantages compared with other medical imaging techniques: it is noninvasive, does not produce ionized radiation, and it is inexpensive. In a standard echocardiographic examination, four basic modes of operation are distinguished according to the European Association of Echocardiography [1]: B, M, color Doppler, and pulse/continuous Doppler modes. The B and color Doppler modes display a 2-D image that represents the heart and its movements. The color Doppler mode also shows velocity of the blood-flow by using a color code. The M mode represents a 1-D view of the cardiac structures moving over time. The pulse/continuous Doppler mode permits taking velocities measurements in a specific section of the heart

The cardiovascular diseases are the main cause of death

in developing countries and, hence, it is very important to have access to echocardiogram exams anytime and anywhere. In tele-echocardiography systems, the echocardiogram is performed in a remote location by a sonographer and the echocardiogram is sent to the expert cardiologist who visualizes the echocardiogram in real-time and makes the diagnosis. With emerging wireless technologies, patients may access healthcare services anywhere. However, wireless channels are band limited, time varying, and error prone. Thus, the main challenges in the real-time tele-echocardiography systems with wireless access are:

- Compression should be applied before transmission without losing the diagnostic information in order to reduce the used bandwidth and to facilitate transmission.
- The errors produced by the channel may affect the clinical quality of the echocardiogram. Hence, a reliable method is necessary in order to reduce the errors without introducing excessive delay.

Previous solutions dealt with these challenges separately. In [2], we proposed a Set Partitioning in Hierarchical Trees (SPIHT)-based echocardiogram compression method that employs various codification approaches depending on the visualization characteristics of each mode. The minimum transmission rate to guarantee adequate clinical quality for each mode of operation was evaluated. These requirements were very low compared to previously reported results for ultrasound video compressed with H.264/AVC and Xvid codecs and for the compression with 3-D SPIHT without distinguishing visualization characteristics. We also proposed [3] a reliable method for the echocardiograms transmission where retransmissions and forward error correction (FEC) techniques were combined depending on the channel conditions. The method produced better results than the retransmissions and FEC techniques applied separately. Better results could be achieved if both proposed techniques were used together for the echocardiogram transmission.

In this paper, we present a new approach to improve

the echocardiogram real time transmission over WiMAX channels combining the techniques proposed in [2,3]. Several modifications are implemented in order to enable both techniques to perform correctly when applied jointly.

2. Materials and methods

2.1. Encoding

We proposed [2] a compression technique for echocardiogram transmission that takes into account the visualization characteristics when compressing an echocardiogram. The echocardiogram modes may be divided into two types according to the visualization: the 2-D modes and the sweep modes. Various compression techniques and recommended transmission rates that guarantee diagnostic quality were proposed for each visualization mode.

The 2-D modes represent a 2-D vision of the moving heart. They are, for example, the B and color Doppler modes. The 2-D modes are compressed with 3-D SPIHT algorithm. The resolution time (number of frames that are codified together) is 16 frames. The minimum transmission rate to guarantee diagnostic quality for the 2-D modes is 200 kbps, as recommended in [2]. Due to the block length (16 frames in a block), the blocks are fragmented for transmission into N packets (each containing X bytes). If all packets of the block (N packets) reach the receiver, an adequate diagnosis is possible. Otherwise, the 2-D modes are visualized with inferior quality and an adequate diagnosis is not guaranteed.

The sweep modes represent 1-D view of the heart over time. One new slice is visualized every frame, leaving the remaining image as the previous frame. They are, for example, M and pulse/continuous Doppler modes. For the sweep modes, only the new image slice that appears in a frame is compressed with the 2-D SPIHT algorithm. The resolution time for the sweep modes depends on the swept speed (4 frames for an average speed). The minimum transmission rate of 40 kbps guarantees diagnostic quality for the sweep modes, as recommended in [2]. Since the blocks (1 slice in a block) have a small length, fragmentation is not necessary.

2.2. Transmission protocol and monitoring process

In [3], we designed a reliable application layer protocol over User Datagram Protocol (UDP) that uses retransmissions or both retransmissions and FEC techniques, depending on the channel conditions for the 2-D modes. The errors produced by the channel may affect the 2-D modes more than the sweep modes because the 2-D modes require

a higher transmission rate. For the sweep modes, we propose using only retransmissions because their transmission rate are very low compared to the 2-D modes and, consequently, to the required channel bandwidth. This leads to fewer errors and shorter transmission time, permitting more time for retransmissions.

In order to adapt the protocol to the channel conditions, two operation states were proposed [3]. The model begins with “good state”. When more than 5 % of packets are not successfully received, the model enters “bad state”. When less than 2 % of packets are not successfully received, the model enters “good state” again. The reliable methods used in each state are:

- “Good state”: retransmission for both modes.
- “Bad state”: retransmissions for the sweep modes and retransmissions combined with FEC code for the 2-D modes.

Both retransmissions and FEC techniques introduce additional transmitted bits. The FEC uses the Reed–Solomon (RS) code, which is a systematic block code. The RS code is applied to N packets that correspond to a block so that they do not introduce additional coding delay and to avoid the effects of burst errors. The RS code generates K packets, N packets of the coded video and $N - K$ packets of the correction packets. The K packets are transmitted through the network.

However, Y packets arrive at the receiver. If N or more packets arrive correctly, the RS code is able to recover the lost packets and the video is visualized with guaranteed quality. Otherwise, the RS code is unable to recover the lost packets and the video is visualized with inferior quality and, thus, an adequate diagnosis is not guaranteed.

In order to efficiently implement retransmissions, a monitoring buffer has to be used at the reception site. It enables the continuous flow of data when a packet is retransmitted. Two buffers are implemented: a reception buffer that contains all packets that arrive to the receiver and a monitoring buffer that contains the decoded frames that are visualized. The echocardiogram is visualized in reception after buffer time (T_B) seconds since the first packet is received. The video is visualized without stops. The value of T_B is selected by the user.

2.3. Quality parameters

The following parameters measure the quality of the proposed method:

- *Bandwidth (BW)*: It quantifies the number of bits per second (bps) used in the communication.
- *Percentage of time with guaranteed clinical quality (%t)*: This is the percentage of the time that the video is

Table 1. Time distribution of electrocardiograms.

Device	Video	Time (s)	% time		
			2-D	Sweep	Stop
Sonosite Elite	1	1901	60%	24%	16%
	2	1816	56%	15%	29%
	3	2064	81%	7%	12%
Philips Envisor	4	1653	90%	9%	1%
	5	2126	78%	3%	19%
Philips IE33	6	1860	79%	20%	1%
	7	1965	45%	23%	32%
Philips IE33	8	1895	52%	21%	27%
	9	2087	47%	22%	31%

visualized with the recommended transmission rates. We may assume [3] that the echocardiogram has been received with adequate clinical quality if the percentage of time with guaranteed clinical quality is at least 95%.

- *Delay*: This is the time from the moment when the video is captured until it is monitored in the receiver. It depends mainly on the frame resolution and T_B that is determined by the user.

2.4. Echocardiograms database

Nine echocardiograms from patients with various diagnoses were recorded and stored using three different ultrasound devices by three cardiologists experienced in echocardiography. Three sessions per device were recorded. Each session corresponded to one patient. The devices and the echocardiogram time distribution, total time, and percentage of time for each mode are shown in Table 1. Each device has its specific characteristics. The selected echocardiograms were representative of typical and abnormal findings in the cardiovascular field. The echocardiographic sessions ranged from 27 to 35 minutes. The echocardiograms contained the four basic modes evaluated in [2]. The acquired videos had a frame rate of 25 fps and a resolution of 720x576 pixels.

The nine videos are sent with transmission rates of 200 kbps, 40 kbps, and 0 kbps for 2-D modes, sweep modes, and stops respectively. In addition to these nine echocardiograms, an echocardiogram of 30 minutes duration and without distinguishing visualization modes has been transmitted (named video 0). This video is compressed with 3-D SPIHT, as the 2-D modes, and consequently its transmission rate is 200 kbps. Each video is sent with the proposed reliability method and without reliability. Each simulation has been repeated 4 times and performed for different buffer times T_B .

Table 2. WiMAX configuration parameters.

Parameter	Value
Access technology	OFMA 5 MHz
Base frequency	2.5 GHz
Frame/symbol duration	5 ms/100.8 μ s
Modulation and coding	QPSK 1/2
Duplexing technology	TDD
Max./Min. traffic rate	1 Mbps/0.5 Mbps
Max. latency	30 ms
Multipath channel model	ITU pedestrian A
Pathloss model	Suburban Fixed (Erceg)

2.5. Simulation scenario and setup parameters

The simulated scenario [4] is shown in Fig. 1. The patient who lives in a remote area does not need to travel to the hospital where the expert cardiologist usually performs only the follow-up and early diagnosis of cardiovascular diseases. The echocardiogram is performed at a remote location with a fixed WiMAX access connected to the Internet. The echocardiogram is then sent in real-time to the expert cardiologist located in a hospital with an ADSL access where the diagnosis is made.

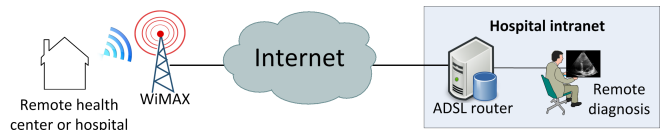


Figure 1. Scenario of tele-echocardiography with fixed WiMAX access.

The simulation scenario has been created using OPNET Modeler. The WiMAX (IEEE 802.16e) configuration parameters are shown in Table 2. The distance between the access point and the WiMAX base station is 1 km. The WiMAX base station is connected to the Internet via a Digital Signal 3 (DS3) Wide Area Network (WAN) link (44.736 Mbps). The hospital intranet has a router that connects to the Internet cloud through a DS3 link. The hospital intranet has a bandwidth of 100 Mbps. The WiMAX base station is located in Vancouver while the hospital is in Toronto. The approximate distance between the two subnets is 3,342 km, which corresponds to approximately 11.1 ms propagation delay. The packet loss ratio in the Internet cloud is 0.001 %. The cloud adds 1 ms delay in addition to the propagation delay of the WAN link.

The blocks for the 2-D modes are fragmented into packets of 800 bytes ($X = 800$ bytes), having a total of 20 packets ($N = 20$ packets) per block [(16 000 bytes/block) / 800 bytes/fragment]. An important parameter is also the correction code. A correction of 40 % has been chosen (K

Table 3. Quality parameters without using reliability

Videos	0	1	2	3	4	5	6	7	8	9
BW (kbps)	200	130	129	171	184	158	159	94	114	101
%t	64	76	76	69	66	71	71	83	79	80

= 28 packets).

3. Results and discussion

The bandwidth and percentage of time with guaranteed clinical quality for the ten videos (video 0 is without compression by modes) and without using reliability are shown in Table 3. The echocardiogram is visualized a higher percentage of time with guaranteed clinical quality while less bandwidth is used for the videos compressed using the proposal based on visualization modes. Furthermore, the lower the bandwidth, the higher is the percentage of time. Video 4 has the highest bandwidth and the lowest percentage of time because the 2-D modes are more present than in the remaining videos.

The percentage of time with guaranteed clinical quality is listed in Table 4 while the bandwidth for the ten videos and T_B of 0.4, 0.45, and 0.5 s are listed in Table 5. For the bandwidth, only a T_B of 0.5 s is shown because the results are very similar for the three values that differ by less than 1 kbps. Comparing Table 4 and Table 3, shows that the percentages of time when using reliability are considerably higher than without it. However, if the visualization modes are taken into account for the compression process, better percentages of time are achieved. The results dependent on the time distribution of echocardiograms. The echocardiogram compressed with the proposed method has been received with adequate clinical quality (at least 95 % of time with guaranteed clinical quality) saving from 50 ms to 100 ms of delay with respect to the case without considering modes. An exception is one echocardiogram (video 6) when no saving is achieved. Video 6 presents the worst percentage of time because of the low percentage of stops in the time distribution of echocardiogram. More bandwidth is used with reliability than without it, in order to protect the transmission from the errors introduced by the network. However, less bandwidth is used with compression and with distinguishing visualization modes. The used bandwidth highly depends on the presence of 2-D modes in the video.

4. Conclusions

The echocardiogram transmission using the compression method based on visualization modes achieves lower bandwidth requirements for the available database records.

Table 4. Percentage of time with guaranteed clinical quality and reliability.

T_B (s)	Videos									
	0	1	2	3	4	5	6	7	8	9
0.40	92	94	95	94	93	94	92	95	94	94
0.45	94	95	96	96	95	96	94	97	95	96
0.50	96	96	98	97	96	97	96	97	96	97

Table 5. Bandwidth using reliability.

Videos	0	1	2	3	4	5	6	7	8	9
BW(kbps)	307	182	198	262	278	243	240	141	163	148

As a result, it achieves better transmission performance than compressing the echocardiograms without distinguishing the visualization modes. Furthermore, if reliability adapts to the channel performance, the transmission is enhanced allowing adequate clinical quality and reducing the delay visualization up to 100 ms.

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