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Fragility Issues of Medical Video Streaming over 802.11e-WLAN m-health Environments

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Abstract— **This paper presents some of the fragility issues of a medical video streaming over 802.11e-WLAN in m-health applications. In particular, we present a Medical Channel-Adaptive Fair Allocation (MCAFA)scheme for enhanced QoS support for IEEE 802.11 (WLAN), as a modification for the standard 802.11e Enhanced Distributed Coordination Function (EDCF) is proposed for enhanced medical data performance. The Medical Channel-Adaptive Fair Allocation (MCAFA) proposed extends the EDCF, by halving the contention window (CW) after ζ consecutive successful transmissions to reduce the collision probability when channel is busy. Simulation results show that MCAFA outperforms EDCF in-terms of overall performance relevant to the requirements of high throughput of medical data and video streaming traffic in 3G/WLAN wireless environments.**

I. INTRODUCTION AND MOTIVATION

M-Health can be defined as ‘mobile computing, medical sensor, and communications technologies for healthcare’ [1]. This emerging concept represents the evolution of e-health systems from traditional desktop ‘telemedicine’ platforms to wireless and mobile configurations. Current and emerging developments in wireless communications integrated with developments in pervasive and wearable technologies will have a radical impact on future healthcare delivery systems. In this paper, we present an advanced mobile healthcare application example (mobile robotic tele-echography system) that requires a demanding medical data and video streaming traffic in heterogeneous network topology that combines 3G and IEEE 802.11e EDCF QoS WLAN environments.

3G cellular technology is characterised by increased area coverage which is their biggest advantage. On the other hand, 802.11 WLAN, offers high bandwidth connections at low cost but in limited range. These two main stream wireless access methods, have dominant the wireless broadband Internet market. However the most probable application scenario, is the coexistence of both. Tele-medicine is one of the multimedia application that will benefit from this scenario.

The advanced medical robotic system - OTELO (mObile-Tele-Echography using an ultra-Light rObot) was a European IST funded project that develops a fully integrated end-to-end mobile tele-echography system for population groups that are not served locally, either temporarily or permanently, by medical ultrasound experts. It comprises a fully portable tele-operated robot allowing a specialist sonographer to perform a real-time robotised tele-echography to remote patients [2].

OTELO is a remotely controlled system designed to achieve reliable ultrasound imaging at an isolated site, distant from a specialist clinician [3]. Fig 1 shows the main operational blocks. This Tele-echography system is composed of the following:

- An “expert” site where the medical expert interacts with a dedicated patented pseudo-haptic fictive probe instrumented to control the positioning of the remote robot and emulates an ultrasound probe that medical experts are used to handle, thus providing a better ergonomy.

- The communication media. We developed communication software based upon IP protocol to adapt to different communication (wired and wireless links).

- A “patient” site made up of the 6 degrees of freedom (Dof) light weight robotic system and its control unit.

Further details on this system are described in [1,2].

With recent advances in mobile technologies, WLAN, PDAs and other hand-held devices featured with different software and hardware capabilities are used by physicians, nurses and other paramedical staff to be updated with the medical reports of patients over the air interface. In this paper, OTELO is integrated in a 3G/WLAN environment so that the health care professional who are on the move, might have continuous access to the patient information. IEEE 802.11e employs a Medium Access Control (MAC), based on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). The collision avoidance mechanism utilizes the random back-off prior to each frame transmission attempt. It is known that the throughput performance of 802.11e WLAN is significantly compromised as the number of stations increases. As the number of WLAN devices used in OTELO increases, the random nature of the back-off reduces the collision probability, but cannot completely eliminate collisions. This motivates us to propose a new scheme termed Medical Channel-Adaptive Fair Allocation (MCAFA), which combines service differentiation, gentle Contention Window (CW) decrease and an adaptive access scheme.

This paper is organized as follows, where, the performance analysis of the expert side medical data of the OTELO system over the WLAN environment is presented (Fig 2). The functional modalities of the OTELO system over the 3G link is presented in Section II. Quality of Service (QoS) over UMTS and WLAN for medical images is investigated in Section III. MCAFA is proposed in Section III. Numerical and simulation results are given and discussed in Section IV. Finally, we draw our conclusions in Section V.

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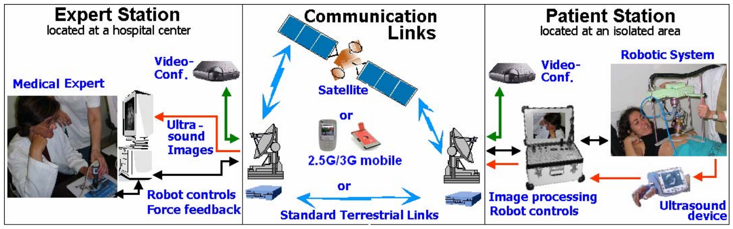

Fig. 1. The OTELO Mobile Robotic System

II. OTELO FUNCTIONAL MODALITIES AND WIRELESS CONNECTIVITY

OTELO can be considered as a bandwidth-demanding data traffic with different classes of QoS requirements. These have to be transmitted simultaneously. Fig 2 shows the general 3G - WLAN connectivity of the OTELO system and the interface requirements. In this scenario, we assume that the OTELO's Expert Station is connected to the OTELO system via the specialist hospital WLAN network.

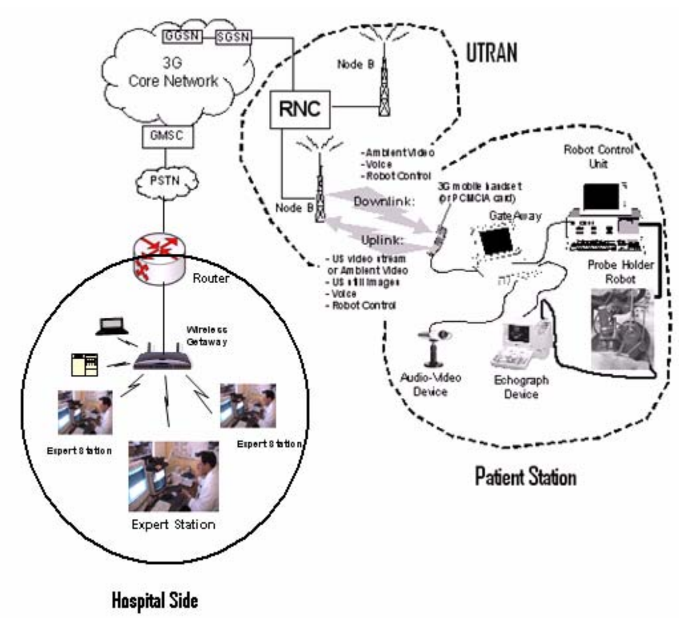

Fig. 2. The Wireless OTELO connectivity scenario with WLAN hospital connectivity

The detailed medical and non-medical OTELO data traffic are shown in Table I. As the ultrasound images are mostly transferred from the robot probe to the OTELO Expert Station, the air interface, Uu, between the OTELO Patient Station and the Radio Network Controller (RNC) bearer is asymmetric traffic load. The still ultrasound images, stream ultrasound images, ambient video, sound and robot control data are sent over the uplink channel, while only robot control, ambient video and sound need to be downloaded to the patient side (i.e. Expert station uploading). It is well-known that for WLAN (IEEE 802.11e), the medium access control (MAC) protocol is the key component that provides the efficiency in sharing the common radio channel, while satisfying the QoS requirements of various multimedia traffic. From this table, it can be seen that for OTELO system the most bandwidth-demanding traffic is the medical ultrasound data.

According to the communication link limitations various scenarios can be identified with respect to the data traffic that should be sent simultaneously so as to enable the performing of the medical examination. For our experiments we consider the two following options:

i) When the expert is searching for a specific organ (liver, kidney, etc.), high quality images may not be required: simple compression methods or lossy techniques can be applied. The lowest data rate acceptable to medical experts is 210kb/s with a frame update of 15 fps.

ii) When the organ of interest is found and small displacements of the robot are appealed, it may be necessary to consider lossless compression techniques that would bring higher image quality to the expert. This lossless compression can be applied on the whole image or on an area of interest (A.O.I.). Form the medical perspective and in order to provide a real-time virtual interactivity between the remote consultant and the manipulated robot, the best round trip delay from the expert station between the robot commanded position and the received corresponding image should not exceed 300 ms.

III. THEORETICAL LINK CAPABILITIES AND QUALITY OF SERVICE FOR MEDICAL IMAGES

In this paper, the focus is on ultrasound media video streaming related as it is the critical data for this m-health advanced application.

A. Universal Mobile Telecommunications Service (UMTS)

According to the International Telecommunications Union (ITU) requirements, the data rate that will be available over 3G will depend upon the environment the call is being made in. We focus on the two options that are more likely to be used in the framework of OTELO when considering a mobile patient station within a rescue vehicle:

High Mobility: 144 kbps for rural outdoor mobile use. This data rate is available for environments in which the 3G user is travelling more than 120 kilometres per hour in outdoor environments.

Full Mobility: 384 kbps downlink for pedestrian users traveling less than 120 kilometres per hour in urban outdoor

	Ultrasound video	Ultrasound still images	Ambient video stream	Voice	Robot control Data
Flow direction	Simplex: Patient to Expert	Simplex: Patient to Expert	Duplex	Duplex	Duplex
Transport Protocol	RTP/UDP/IP	TCP/IP	RTP/ UDP/IP	RTP/ UDP/IP	UDP/IP
Speed Requirement	Real-time	Non Real-time	Real-time	Real-time	Real-time
Payload data rate requirement	15 frames/s@ 210 kbit/s	1 frame/ 10s Uplink	15 to 1 frame/s symmetrically	16 kbit/s symmetrically	0.3 kbit/s symmetrically

Table I: OTELO medical data requirements and corresponding data rates.

environments. From the previously defined bandwidth requirements (Table I) the classification of the OTELO traffic is mapped to the three major traffic classes defined by the 3GPP UMTS QoS Classes [4]. The best-suited UMTS QoS class for video streaming is "Streaming class, streaming RT" which preserve time relation (variation) between information entities of the stream. But for medical image sequence with real-time requirements, the "Conversational RT" class would be necessary[3]. In addition to preserving time relation between entities of the stream, it has conversational pattern (stringent and low delay) which is preferable for a real-time interaction.

B. WLAN (IEEE 802.11e EDCF)

An 802.11e station can implement four access categories (ACs), where each packet arriving at the MAC layer with a priority is mapped into an AC with separate queue. EDCF provides service differentiation through contention windows (CWs) and arbitration inter-frame spaces (AIFSs). It assigns a smaller CW and shorter AIFS to higher priority classes, resulting in lower mean waiting and back-off times than lower priority classes. If there is more than one queue finishing the back-off at the same time, the highest AC frame is chosen to transmit by the virtual collision handler. Other lower AC frames whose back-off counters also reach to zero will increase accordingly. A station cannot transmit a frame that extends beyond the Transmission Opportunity (TXOP) Limit which is defined as the interval of time when it has the right to initiate transmissions. (Please see Table II)

C. Medical Channel-Adaptive Fair Allocation (MCAFA)

According to the channel status, the MCAFA operates as follows:

Idle Stage: All priority queues in the different active stations monitor the medium. If a queue i senses that the medium is idle for a slot, then it will start decrementing the back-off timer by a Slot Time (ST) as in the IEEE 802.11e specification.

Collision Stage: If a queue notices that its packet transmission has failed due to a packet collision, the queue will double its current contention window, $CW_{i,j}$ and update its back-off time, $BT_{i,j}$

Successful Transmission Stage: When a queue successfully transmit a packet for ζ consecutive transmissions, it will halve the $CW_{i,j}$, update its $BT_{i,j}$ and reset the successful transmission counter. Otherwise, MCAFA increases the counter and keeps $CW_{i,j}$ unchanged.

IV. Numerical and Simulation Results

A. Simulation Setup

As mentioned above our concern for this m-health application is the expert side, which is the the WLAN part. We simulated this part of the OTELO system using NS-2 software tool. We simulated the medical ultrasound traffic that the experts hospital side received and send as shown in table below. Each station sends three different flows (Voice, ambient video stream and robot control data as shown in Table I) to a the patient station.

	Voice	Video	Data
Transport	UDP	UDP	UDP
Priority	7	5	0
AIFSN	1	1	2
CW_j^{min}	7	15	31
CW_j^{max}	15	31	1023
$TXOP_{Limit}$ (msec)	3	5	0
Flow Rate (kbps)	16	50	0.3

Table II: EDCF Flow Parameters

B. Results and Analysis

Figures (3 - 8) show the results for the global throughput, throughput of traffic class, frame discard probability and average delay of the proposed scheme.

Figure (3) shows the effect with increase number of stations on normalised throughput. Normalised throughput is defined by the serviced bit rate normalised to the required bit rate of the corresponding class. This shows that there is a considerable throughput enhancement with high number of contending stations. MCAFA throughput gain decreases when the number of contending stations but it keeps outperforming EDCF.

In figure (4), based on QoS differentiation, throughput of ultrasound video is higher than that of voice and data. These results shows that the MCAFA differentiates the traffic classes and supports priority access and hence provide higher throughput. We observe that the new scheme protects the throughput of the three traffic classes for all channel loads, while the throughput deteriorates in moderate and high load cases with EDCF.

The frame discard probability of packets happens in two cases that the number of retransmission exceeds a predefined retry limit and the delay of packet is longer than the delay bound. In figure (5), this probability of the video class is the highest followed by voice and data, which implies that MCAFA supports packet loss differentiation. In addition, the higher the retry limit is the lower the discard probability.

In the case of high load, we observe that with the MCAFA scheme (See Figure (6)), packets experienced maximum delays of 5.9s for voice, 7.9s for video and 5.6s for data traffic, while with EDCF, packets experience delays of 7.9s for voice, 9.92s for video and 6.9s for data, which is much higher than that of our proposed scheme.

As shown in figure (7), there is a 110% improvement gained by MCAFA as compared to the fragile EDCF mechanism. The reason is because the ζ threshold function allows all competing stations to stay in the same back-off stage with high probability. This provide better fairness between different stations since the queues of the different stations will be transmitting at the same contention window (CW_j) concurrently. However, EDCF double the CW_j values in the collision stage, which results in a slow increase in the CW_j values and hence in a large variability in the CW_j values among the stations. The large variability in the CW_j values leads to a problem of fairness at short time scales. Compared to EDCF, the collision resolution mechanism used by MCAFA provide robust performance and can greatly avoid collisions as shown in figure (8 in which collision rates vs number of stations are observed.

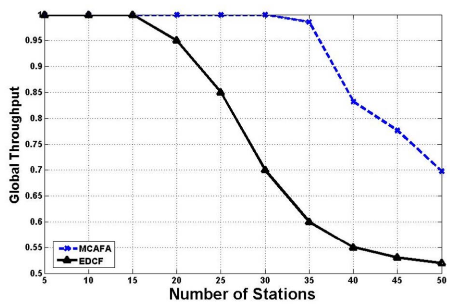

Fig. 3. Performance of the Global Throughput vs Number of Stations

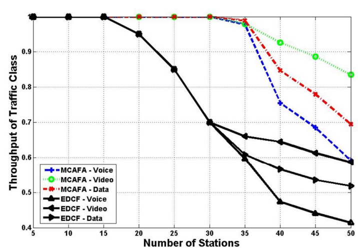

Fig. 4. Performance of the Throughput of Traffic Class vs Number of Stations

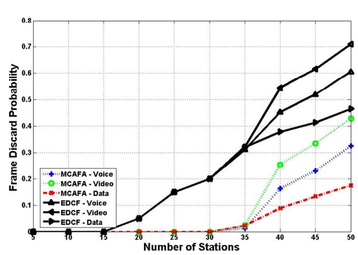

Fig. 5. Performance of the Frame Discard Probability vs Number of Stations

V. Conclusion

In this paper, a new Medical Channel-Adaptive Fair Allocation (MCAFA) that extends the basic EDCF 802.11 scheme is presented. The new scheme provides a robust throughput performance compared to existing fragile EDCF system. Ongoing work is currently underway to test the system on real-time mobile robotic ultrasonography system in hospital settings. The presented method can improve the performance of similar m-health systems in different medical applications.

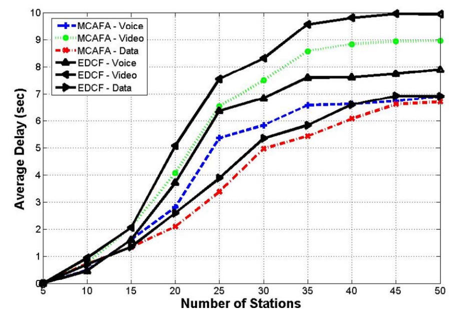

Fig. 6. Performance of the Average Delay vs Number of Stations

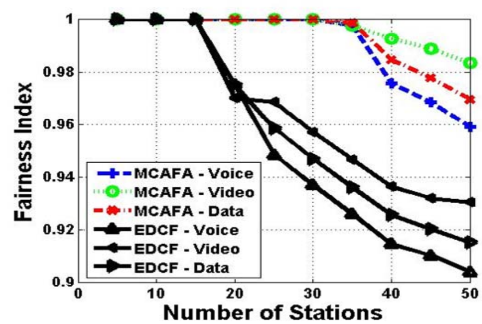

Fig. 7. Performance of the Fairness Index vs Number of Stations

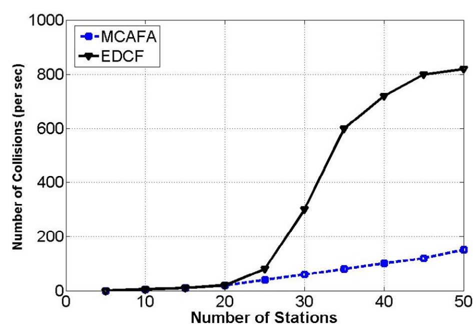

Fig. 8. Performance of the Number of Collisions vs Number of Stations

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