Video-Aware Relay Selection in Single-Carrier and OFDM Wireless Systems

Dimitrios Kosmanos*, Antonios Argyriou*†, and Leandros Tassiulas*†
*Department of Electrical and Computer Engineering, University of Thessaly, Volos, Greece
†The Center for Research and Technology Hellas (CERTH), Thessaloniki, 57001, Greece

***Abstract*—In this paper we consider packetized video transmission in cooperative relay-based wireless networks. We propose algorithms for optimized relay selection that take into account the content of each specific video packet. Our first algorithm, that is designed for a narrowband flat-fading channel and single-carrier modulation, selects jointly the optimal relay and video packet for forwarding. Our next algorithm is an extension of our main idea for OFDM modulation that is suitable for frequency-selective fading channels. In this case in addition to optimized packet and relay selection, our algorithm also jointly selects the optimal power level for each subcarrier. The key benefit of our algorithms is that they are fully distributed since they require no explicit communication among the relays but they only use passively collected information. We perform an extensive evaluation of our algorithms for different system configurations.**

***Index Terms*—Cooperative systems, relay selection, wireless video, utility optimization, packet overhearing, rate allocation, cross-layer optimization, OFDM.**

I. Introduction

High quality video streaming in wireless networks is one of the hottest mobile applications today. The widespread adoption of mobile devices that are capable of handling sophisticated and high data-rate wireless communication algorithms is propelling this demand. The video traffic explosion in wireless networks is expected to accelerate even more [1]. To address this massive demand for high quality video, mobile network operators have several options in their arsenal. One is the deployment of relay nodes at different locations within the coverage area of a single cell. Relays can be deployed in small-cell configurations in order to process the received signal from the base station (BS) before forwarding it to the destination (Fig. 1). This type of cooperation among different network nodes provides a flexible alternative to the use of multiple antennas in order to create diversity for the transmitted signals and lead eventually to higher throughput [2]. Although cooperative diversity with relays has been investigated considerably from a theoretical perspective, in the immediate future the prospects of being implemented are better than ever precisely because of the high demand for increased bandwidth and coverage. Many standards like LTE-Advanced and WiMaX, support relay-based transmission modes that have been shown to be practical [3].

Wireless cooperative transmission of video streams has been studied in the literature considerably the last few years but the term *cooperative transmission* may span techniques applicable at different layers of the protocol stack. The case of layered encoded video in conjunction with the novel PHY technique of distributed space-time coding (DSTC) was studied in [4]. DSTC was employed in that work in order to improve the decoding of the PHY symbols when multiple receivers are involved. One important issue that must be addressed in DSTC is that the relays must transmit simultaneously which means perfect synchronization is required. Furthermore, the signal diversity benefits of DSTC can also be achieved in a distributed network with simpler protocols according to which it is enough to select the relay with the best channel [2]. An important observation is that the previous schemes focus on using a cooperative transmission approach for increasing the reliability of packet transmissions that eventually translates to higher throughput/video quality. However, the potential performance impact of embedding video-awareness into the relay selection process has not been investigated very thoroughly. Recently, there are some works towards this direction. In [5] the authors proposed the cooperative relay selection by modeling the system as an Markov Decision Process (MDP). The communication model considers only uplink transmissions towards an access point (AP). Even though the approach minimizes information exchange between networks nodes, still there is a need for message passing rounds between the relays and the AP.

Further study of the problem of video-aware relay selection reveals that it is unexplored when we consider relays that use advanced modulation schemes like orthogonal frequency division multiplexing (OFDM). Research works that propose embedding video-awareness in OFDM systems do not consider the case of cooperative transmission based on relays. In [6]

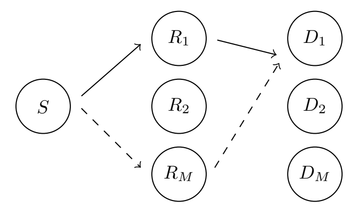


Fig. 1. Cooperative network model that includes a source, a number of relays and destinations. Here, only the packet flow towards D_1 is shown to avoid clogging the figure. The dashed lines indicate the overheard packets from a helping relay.

Antonios Argyriou would like to acknowledge the support from the European Commission through the Marie Curie Intra-European Fellowship WINIE-273041.

the authors considered uplink streaming over OFDM. In [7], [8] the authors considered the problem of OFDM subcarrier power allocation for wireless real-time encoded video in a downlink scenario and without relays. Finally, another aspect of the OFDM-based video transmission schemes that can be found in the literature is that the power allocated to the subcarrier is independently allocated from the content of the video packet that is transmitted. For example in [9], [10] the authors considered an ordering of the subcarriers depending on the channel fade.

In this paper, we target the optimized video delivery in a wireless cooperative network (Fig. 1). We propose a fully distributed relay selection algorithm that incorporates into the relay selection process the video content of the packet to be transmitted. Our scheme first selects the best relay from a set of M available relays and then uses this relay for cooperation between the source and the destination. Our method is *fully distributed* and requires no topology information and exchange of special messages between the relays. Only passively collected local measurements of the channel state is used at the relays. This approach is also extended for an OFDM modulation scheme. In this later case besides the video-aware relay selection, we jointly optimize the allocated power to each subcarrier depending on the video content of the packet that requires transmission. Thus, our concrete contributions are two:

1) Our first contribution is that we propose an algorithm for video-aware optimized relay selection in cooperative systems that requires no information exchange between the relays and any other node.
2) Our second contribution is that we propose a relay selection algorithm for OFDM-based cooperative systems that jointly executes with the relay selection task the subcarrier power allocation that is video-aware.

II. System Model and Assumptions

Network Model: In this paper we consider the unicast streaming of a set $\mathcal{N}$ of N pre-compressed video streams from a single source node to N destination nodes that each one is interested in a specific video stream. Besides the source and the destinations, the network also includes a set $\mathcal{R}$ of M relays (it may be that $M > N$) that their task is to aid by forwarding traffic to the destinations as seen in Fig. 1. We assume that the M neighboring relays are densely deployed as shown in Fig. 1 and they can overhear each other.

Video source rate adaptation and Packet Transmission: The source s multiplexes the packets of different flows and broadcasts them to the relays. The source transmits video flow n at rate r_n. We apply rate adaptation in order to calculate the streaming rate r_n that is optimal for each flow n given the end-to-end available data rate [11]. To accomplish that, the packet error rate information is periodically collected at the source (e.g. through RTP messages) and then the source executes a rate allocation algorithm to derive the optimal r_n^*. Since we perform rate adaptation/allocation at the source based on information for the complete end-to-end channel, we know that all the packets that are transmitted from the source should reach the destination and not be dropped. Therefore, the relays know that they must transmit all the packets in their FIFO buffer (this behavior is similar to employing TCP).

Video Content Model: The rate-distortion (R-D) information associated with packet i is contained in each packet header and it consists of its size $\Delta R(i)$ in bytes, and the importance of the packet for the overall reconstruction quality of the media presentation denoted as $\Delta D(i)$ [12]. In practice, $\Delta D(i)$ is the total increase in the mean square error (MSE) distortion that will affect the video stream if the packet is not delivered to the client by its prescribed deadline [13]. It is important to note at this point that the value of the MSE distortion in $\Delta D(i)$ includes both the distortion that is added when packet i is lost and also the packets that have a decoding dependency with i[1]. In this way the utility formulation considers also the possible drift that might occur due to the loss of particular packets/video frames.

Channel Access: The channel access scheme employed by the source node/relays follows a simple structure widely adopted in cooperative networks. The basic cooperative protocol separates a single time slot into two phases (see Fig. 2). The source node broadcasts in the first phase. During the broadcast phase the M relays also overhear this transmission. Next, there is one forwarding phase from a relay to destination node. The relay that will obtain access to the channel and transmit, is selected in a distributed fashion as we will describe later in this paper.

Channel Model and PHY Modulation: At the PHY we first assume the use of single-carrier (SC) Phase Shift Keying (PSK) modulation scheme. All the channels are considered to be narrowband block-fading Rayleigh. The channel coefficients are quasi-stationary, that is they remain constant for the coherence time of the channel (slow fading). We denote the channel from the source s to the r-th relay as $h_{s,r}$, and the channel from the r-th relay to destination d as $h_{r,d}$. Additive white Gaussian noise (AWGN) with zero mean and unit variance is assumed at the relays and the destinations. We also assume that each transmitter employs a type of ARQ (e.g. hybrid ARQ) that is typical in cellular and WLAN standards. We also consider OFDM modulation. In the OFDM case the bit sequence that constitutes a single packet is de-multiplexed into each of the used subcarriers. We also assume channel state information at the transmitter (CSIT) is available for both the SC and OFDM modulation schemes.

Packet Overhearing at the Relays: With our system, when a packet is broadcasted from the source node it may be received at an arbitrary number of relays. If the relays are left without coordination they may transmit the same packet to the same destination. To avoid duplicate packet transmission we propose a simple protocol: When a relay forwards a packet to the next hop destination, the remaining relay nodes also overhear this DATA transmission and its acknowledgement

[1]For example the ΔD for an I frame includes the ΔD of the P and B frames that depend on it.

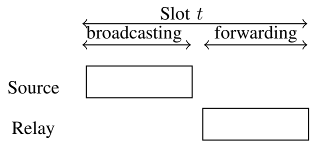


Fig. 2. Behavior of the cooperative protocol in the time domain. Time is slotted and each slot is separated in two phases. Which relay will transmit and what packet are the targets of our optimization in this paper.

through the ACK. By following this approach, the neighboring relays know that if they have the same packet in their buffer, there is no need to transmit it in the next time slot that they obtain the channel. Instead, they discard it if they also overhear this ACK. In case a packet transmission from a relay fails, this is detected by the lack of an ACK message. So all the relays retain the lost packet since any one of them may transmit it in the next opportunity they have. Therefore, this simple overhearing algorithm allows the relays to forward uniquely each video packet to the next hop without exchanging detailed buffer maps regarding the data they have, and with the minimal implementation requirements.

III. Video-Optimized Distributed Relay Selection in a Narrowband Channel

In the case of digital wireless transmission over slow fading channels when the channel is in deep fade the transmitter must employ channel coding and interleaving over many channel coherence periods in order to achieve the ergodic rate of the channel [14]. However, the previous approach introduces significant delays for real-time data transmission. The fundamental approach that addresses this problem is diversity, i.e. the use of many independently transmitted copies of the same information. Cooperative diversity with relays is such a method and we will use it in this paper. Cooperative diversity can be applied in conjunction with relay selection protocols that are responsible for selecting the relay with the best channel. This approach has been shown to be effective in maximizing the diversity benefits even without the use of STC [2]. In this paper cooperative diversity is also employed but *the novelty is that our system identifies not only the optimal relay but also the optimal packet and relay combination from all the available relays and all the received packets at the relays*. The key observation is that because of the broadcast transmissions from the source, the same packet may be available at many relays while the relay that has the best channel towards a destination may not have received an important video packet.

A. Problem Formulation

The last observation that motivates this paper must be converted to a concrete problem formulation. The intuition behind our problem formulation is based on the interpretation of fading events on the channel capacity. More specifically, for a slow fading channel with fading gain h, transmission power P, AWGN with zero mean and variance N_0, and bandwidth W, the Shannon capacity $W\log(1+\frac{P|h|^2}{N_0})$ can be seen as the number of bits/sec that the channel can reliably transmit [14]. Our description of the optimization problem further clarifies the practical use of the previous observation. Let us denote the utility and the length of the current HOL packet at relay r as ΔD_r and ΔR_r respectively. Let also $\vec{x}$ be a vector that contains the activation variables for the involved relays, i.e. x_r is 1 if relay r is selected in the current slot. Thus, the problem of distortion-optimized relay selection over a narrowband fading channel is defined as follows:

$$\text{OPT1}: \quad \max_{\vec{x}} \sum_{r=1}^{M} x_r \frac{\Delta D_r}{\Delta R_r} \log\left(1+\frac{P|h_{r,d}|^2}{N_0}\right)$$

$$x_r \Delta R_r \leq \log\left(1+\frac{P|h_{r,d}|^2}{N_0}\right) \text{ (C1)}$$

$$\sum_{r=1}^{M} x_r = 1 \text{ (C2)}$$

The rationale of this form of the optimization objective is that the utility of the HOL packet is multiplied by the instantaneous rate of that particular relay and the result is a scaled utility metric. This approach couples first the impact of relay selection through x_r, and the ratio $\frac{\Delta D_r}{\Delta R_r}$ of a specific packet, with the instantaneous achievable rate of the Rayleigh slow fading channel. Consider for example two relays with $h_{1,d} < h_{2,d}$. Assuming an optimal capacity-achieving AWGN code relay r=1 can reliably communicate at a rate $\log\left(1+\frac{P|h_{r,d}|^2}{N_0}\right)$ bits/sec. Even if the second relay can reliably communicate more bits, the result is that if a packet of high utility is available at the first relay this specific packet is selected for transmission. A critical observation is that when a packet to be transmitted has size ΔR that is larger than the achievable channel rate, then we cannot reliable communicate this number of bits. This is captured by the first constraint (C1) of problem OPT1. When this constraint is not satisfied this is usually referred to as an outage event. Constraint C2 ensures that only one relay transmits.

B. Distributed Solution with Video-Aware Channel Access and Relay Selection

Now the first question is how to solve this linear program (LP) in a distributed fashion. Calculating the optimal $\vec{x}^*$ would be easy to be performed in a centralized fashion but this is not possible in our case since each relay knows only its local channel estimate $h_{r,d}$. Relay selection is a typical issue that has to be addressed in cooperative wireless networks. In several works this problem has been addressed with simple distributed solutions [2], [15].

In our system, it is implemented as follows. First, when the relay transmits a packet, and the destination transmits an ACK, all the relays estimate the channel towards the destination. Based on the wireless channel reciprocity property the channel gain serves as a good estimate of the forward channel from the relay to the destination [14]. To solve OPT1 in a distributed fashion, a relay calculates the scaled utility, and it accesses the channel by setting a specific timer depending on this value. In particular the timer is set equal to

$$TO_r = \Big\lfloor \frac{1}{\frac{\Delta D_r}{\Delta R_r}\log(1+\frac{P|h_{r,d}|^2}{N_0})}\Big\rfloor, \quad (1)$$

This happens only when C1 is satisfied. In any other case the relay does not contend for the channel and does not set this timer. Now in the case that C1 is satisfied and the relay has set the timer as described before, the result is that this timer will expire first for the relay that has calculated a higher scaled utility value. Fig. 3 depicts this channel access scheme that takes into account the utility of the video packet that is transmitted. Note that the duration of the timer is very small relative to the packet duration (a few PHY symbols compared to a few thousand symbols) and that is why we ignore its duration later in our evaluation.

This is the novel aspect of our approach: The optimal relay is not the one that simply has the best channel h, but the one that has the most important HOL media packet and it can also transmit it reliably without the channel being in outage.

IV. Video-Optimized Distributed Relay Selection for OFDM Modulation

A. Problem Formulation

In our next problem formulation we consider the case that the modulation scheme is OFDM. In this case we have to identify the optimal relay and also the optimal power for each subcarrier that the relay uses. Given a total power budget P Watts and C subcarriers for each specific relay, the task of the relay is to decide what is the power $p_{r,c}$ it must allocate to the c-th subcarrier. Thus, we have:

$$\begin{aligned}
\text{OPT2a}: \quad & \max_{\vec{x},\vec{p}} \sum_{r=1}^{M} x_r \frac{\Delta D_r}{\Delta R_r} \sum_{c=1}^{C} \log\Big(1+\frac{p_{r,c}|h_{r,d}(c)|^2}{N_0}\Big)\\
\text{s.t.} \quad & \sum_{c=1}^{C} p_{r,c} \leq P, \forall r \in \mathcal{R} \text{ (C1)}\\
& x_r \Delta R_r \leq \sum_{c=1}^{C} x_r \log\Big(1+\frac{p_{r,c}|h_{r,d}(c)|^2}{N_0}\Big),\\
& \forall r \in \mathcal{R} \text{ (C2)}\\
& \sum_{r=1}^{M} x_r = 1 \text{ (C3)}\\
& x_r \ \in \{0,1\}, p_{r,c} \geq 0,\ \forall r \in \mathcal{R} \text{ (C4)}
\end{aligned}$$

In this problem formulation the channel gain of each subcarrier c from relay r to the destination d is denoted as $h_{r,d}(c)$. Now the rate that can be achieved depends on the channel gain of each subcarrier c and the power allocated to it. In the utility function of problem OPT2a, the goal is to select the best relay among all given this additional degree of freedom. The first constraint C1 ensures that the power allocated to the C total subcarriers for each relay will not overcome the total power budget P for this relay. The second and third constraints C2, C3 serve the same role as the first and the second constraints of the problem OPT1 for the single-carrier narrowband relay selection case. In particular, these constraints ensure that relay r can reliably communicate with the destination node and that only one relay is used for transmission in a specific time slot.

Solution. To solve the previous problem we note first that there are integer and continuous variables. Thus, it is a non-convex and NP-hard problem to solve. However, we can decouple it into a convex and linear subproblems following the approach in the previous section. We can solve it in three steps as follows.

Step 1: The relay r selects an optimal power allocation by solving the equivalent problem OPT2b we define next:

$$\begin{aligned}
\text{OPT2b}: \quad & \max_{\vec{p}} \sum_{c=1}^{C} \frac{\Delta D_r}{\Delta R_r} \log\Big(1+\frac{p_{r,c}|h_{r,d}(c)|^2}{N_0}\Big)\\
& \sum_{c=1}^{C} p_{r,c} \leq P, \forall r \in \mathcal{R}\\
& p_{r,c} \geq 0,\ \forall r \in \mathcal{R}
\end{aligned}$$

This convex problem formulation identifies the best subcarrier power allocation that considers however the utility of the HOL packet $\frac{\Delta D_r}{\Delta R_r}$. For solving this problem we form the Lagrangian of the convex problem OPT2b:

$$L_r(\lambda,\vec{p}) = \sum_{c=1}^{C} \frac{\Delta D_r}{\Delta R_r} \log\Big(1+\frac{p_{r,c}|h_{r,d}(c)|^2}{N_0}\Big) - \lambda(\sum_{c=1}^{C} p_{r,c} - P),$$

where λ is the Lagrange multiplier. The solution is a variation of the well-known water-filling result. After applying the K.K.T. for relay r we have that the optimal subcarrier power is:

$$p^*_{r,c} = \Big(\frac{\Delta D_r/\Delta R_r}{\lambda^*} - \frac{N_0}{|h_{r,d}(c)|^2}\Big)^+$$

What the above result means is that the optimal power that is allocated from the relay for the transmission of the HOL packet depends on its utility.

Step 2: In the next step, for the calculated solution the relay checks if the packet length complies with the rate constraint (defined as constraint C2 in OPT2a. If this is true then it proceeds to step 3. Otherwise the relay does not contend for the channel since it cannot ensure reliable communication even with an optimal power allocation.

Step 3: Finally, the relays in a distributed fashion contend for the channel similarly with the narrowband channel case, i.e. by setting the timer with the scaled value, as we described previously. In this case the scaled utility depends on the achieved rate over all the OFDM subcarriers.

V. Performance Evaluation

In this section, we present a comprehensive evaluation of the proposed algorithms comprising our framework through simulations. We have implemented both the PHY outlined in Section II, the video streaming system, and the overhearing and relay selection algorithms in Matlab. The number of relay nodes M is kept small since the simulator operates at the PHY symbol level (not packet-level) requiring thus significant

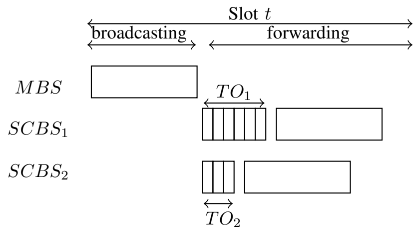
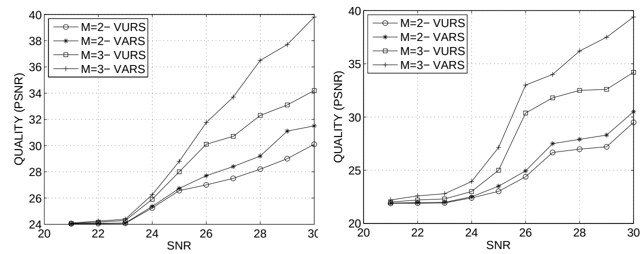


Fig. 3. The timer of the relay with the packet of the highest scaled utility expires earlier obtaining thus first access to the channel.



(a) No ARQ (b) ARQ

Fig. 4. Results for the average system quality when streaming to two destinations the two flows MOTHER & DAUGTHER and FOREMAN.

amount of execution time. Regarding the lower layer parameters we assume a channel bandwidth of W=20 MHz, while the same Rayleigh fading path loss model was used for all the channels. Our assumptions in this case includes a frequency-flat fading wireless link that remains invariant per transmitted PHY frame, but may vary between simulated frames. The noise over the wireless spectrum is AWGN with the variance of the noise to be 10^{-9} Watts/Hz at every node/link. The average channel SNR depicted in the horizontal axis of all the figures was assumed to be the same for all the links but it varied independently during each channel realization. We also enabled the ARQ mechanism for the evaluation of the above systems. These ARQ feedback processes are assumed without error. Note that in all figures we present the utility divided by the number of required time slots for delivering a prescribed media file. This means the impact of ARQ delay is also considered.

The rate allocation at the source was exercised for the duration of 10 GOPs. The media content used in the experiments consists of the CIF sequences MOTHER & DAUGHTER and FOREMAN that were compressed using the SVC H.264 codec [16] at the rates of 203 kbps and 328 kbps, respectively. Each video frame was packetized in one slice. For the experiments with two video flows both sequences were used. A number of 300 frames from each sequence were encoded at a frame rate of 30 fps using the following frame-type pattern IBBBP. The GOP size was set to 32 frames. Also, the startup/playback delay of the video presentation at every node is denoted as d_s. In all the figures, the results correspond to the average PSNR enjoyed by a all relays and the destination for the duration of 300 seconds. Finally we must mention that we did not use any form of error concealment in order to demonstrate clearly the impact of our specific metric/optimization scheme.

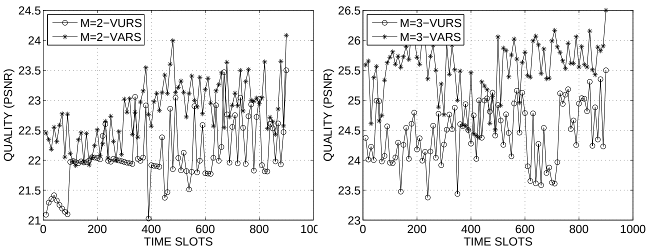
We examine the performance of different system configurations. The first algorithm named video unaware relay selection (VURS) and uses a relay selection scheme that takes into account only the best channel $h_{r,d}$ between the relays and the destination [2]. Our scheme is named video-aware relay selection (VARS). For the simulation of the OFDM system we also used a configuration that is video-unaware and it executes optimal power allocation according to the classic water-filling approach. The previous system is compared to our VARS OFDM-based system. We also examined the effect of using a different number of subcarriers.

A. *Results for a Single-Carrier Narrowband System*

In this section, we study the video quality that can be achieved with all the systems we described before. Results for streaming to two destinations the two video flows can be seen in Fig. 4(a). We also configured a slightly higher startup delay of 5 sec due to bandwidth splitting across the two users. For lower values of the average channel SNR the relay selection schemes show almost the same behavior. This is because in the lower SNR regime the channel is in outage frequently and a packet cannot be transmitted reliably with any scheme. On the other hand, in the higher SNR regime the benefit of VARS is quite significant when compared to VURS. This means that when the channel quality is good, the utility of the video packet is a crucial factor for the optimal relay selection. In particular in this case several relays might have a good channel and so many of them can send a video packet reliably. However, only VARS ensures that this is a packet that has the highest utility. We also evaluated a system where we enabled the ARQ mechanism that typically exists at the link layer (IEEE 802.11, LTE, WiMaX) in Fig. 4(b). In this case we also set d_s=10 seconds to accommodate for the impact of the ARQ mechanism. We see now that the startup delay is increased, and the retransmissions are also allowed, this has impact on the quality of the both systems in a specific channel SNR regime.

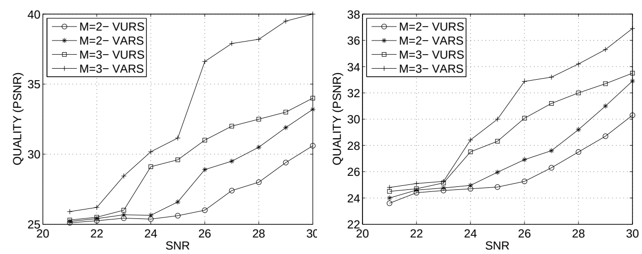
We also measured the real-time value of PSNR at the destination for the case of two and three relays. A value for the average channel SNR of 25dB was used. In Fig. 5 we see that indeed our scheme for VARS can achieve the best real-time video quality when the channel is improved.

Another key benefit of our approach is that it takes into account the precise utility of each video packet. In Fig. 6 we present the average quality for each one of the destination nodes. These results correspond to the case of an enabled ARQ mechanism and M=2,3 relays. As it can be seen in this figure, we can have significantly better results for the video sequence that has packets of higher utility value (in this case FOREMAN). Recall that Foreman has significant motion and so it has packets with higher utility.



(a) M=2 (b) M=3

Fig. 5. Real-time PSNR results for the streaming of the two flows MOTHER & DAUGTHER and FOREMAN when measured at their respective destinations.



(a) FOREMAN (b) MOTHER & DAUGHTER

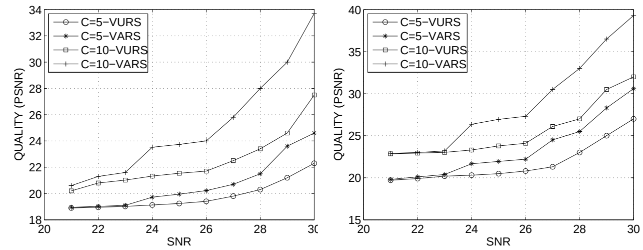
Fig. 6. Comparison of FOREMAN and MOTHER & DAUGHTER.

B. Results for OFDM

In our OFDM experiments, we used M=2,3 relays as intermediate nodes between the source and the destinations while we did not enable the mechanism of ARQ. We also evaluated the effect of different number of subcarriers and more specifically the cases of C=5, and C=10. Generally, with an increase in the number of subcarriers that each relay uses, a smaller PER can be achieved from the relays to destination leading to better quality of video at the destination nodes. In any case, as it can be shown in Fig. 7 with our video-aware algorithm we observed significant improvement in the video quality when compared to the video-unaware OFDM power allocation approach.

VI. Conclusions

In this paper we presented video-aware relay selection algorithms for fading channels with SC and OFDM modulation systems. Our motivating observation is the broadcast nature of the wireless channel that allows the same packet to be available at many relays while the relay that has the best channel towards the destination may not have received an important video packet. To address this problem we proposed an algorithm that selects both the optimal relay and video packet so that the video quality is maximized. Our second contribution is the development of an algorithm that selects not only the optimal relay and packet combinations but also allocates optimally the transmission power to each subcarrier of an OFDM system. Significant performance improvements were observed for all the proposed systems.



(a) M=2 (b) M=3

Fig. 7. Comparison of the tested OFDM-based systems with different number of relays and subcarriers.

References

[1] Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, February 2012.

[2] A. Bletsas, A. Khisti, D. P. Reed, and A. Lippman, "A simple cooperative diversity method based on network path selection," *IEEE Journal on Selected Areas in Communication*, vol. 24, no. XX, p. 659672, March 2006.

[3] Y. Yang, H. Hu, J. Xu, and G. Mao, "Relay technologies for wimax and lte-advanced mobile systems," *Communications Magazine, IEEE*, vol. 47, no. 10, pp. 100–105, 2009.

[4] O. Alay, Z. Guo, Y. Wang, E. Erkip, and S. Panwar, "Enhanced parity packet transmission for video multicast using r-dstc," in *IEEE PIMRC*, 2010.

[5] N. Mastronarde, F. Verde, D. Darsena, A. Scaglione, and M. van der Schaar, "Transmitting important bits and sailing high radio waves: A decentralized cross-layer approach to cooperative video transmission," *Selected Areas in Communications, IEEE Journal on*, vol. 30, no. 9, pp. 1597–1604, 2012.

[6] D. Wang, L. Toni, P. Cosman, and L. Milstein, "Uplink resource management for multiuser ofdm video transmission systems: Analysis and algorithm design," *Communications, IEEE Transactions on*, vol. 61, no. 5, pp. 2060–2073, 2013.

[7] G.-M. Su, Z. Han, M. Wu, and K. Liu, "A scalable multiuser framework for video over ofdm networks: Fairness and efficiency," *Circuits and Systems for Video Technology, IEEE Transactions on*, vol. 16, no. 10, pp. 1217–1231, 2006.

[8] H. Ha, C. Yim, and Y. Y. Kim, "Cross-layer multiuser resource allocation for video communication over ofdm networks," *Comput. Commun.*, vol. 31, no. 15, pp. 3553–3563, Sep. 2008. [Online]. Available: http://dx.doi.org/10.1016/j.comcom.2008.05.010

[9] L. Toni, P. Cosman, and L. Milstein, "Channel coding optimization based on slice visibility for transmission of compressed video over ofdm channels," *Selected Areas in Communications, IEEE Journal on*, vol. 30, no. 7, pp. 1172–1183, 2012.

[10] C.-H. Chen, C. Fung, and S.-J. Wang, "Packetized video transmission for ofdm wireless systems with dynamic ordered subcarrier selection algorithm," in *Acoustics, Speech and Signal Processing, 2009. ICASSP 2009. IEEE International Conference on*, 2009, pp. 1993–1996.

[11] A. Argyriou, "Compressed video streaming in cooperative wireless networks with interfering transmissions," *IEEE Transactions on Communications*, vol. 60, no. 11, pp. 3407–3416, November 2012.

[12] J. Chakareski, J. Apostolopoulos, S. Wee, W.-T. Tan, and B. Girod, "Rate-distortion hint tracks for adaptive video streaming," *IEEE Transactions on Circuits and Systems for Video Technology*, vol. 15, no. 10, pp. 1257–1269, October 2005.

[13] P. A. Chou and Z. Miao, "Rate-distortion optimized streaming of packetized media," *Microsoft Research Technical Report MSR-TR-2001-35*, 2001.

[14] D. Tse and P. Viswanath, *Fundamentals of Wireless Communication*. Cambridge University Press, 2005.

[15] A. Argyriou, "Coordinating interfering transmissions in cooperative wireless lans," *IEEE Transactions on Wireless Communications*, vol. 10, no. 11, pp. 3804–3812, November 2011.

[16] "ITU-T Recommendation H.264, Advanced video coding for generic audiovisual services," May 2003.