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An Optimal Energy Efficient Video Distribution Over Cooperative Wireless Networks

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Abstract: ***Recently supporting real-time video transmission services with diverse QoS constraints has become one of the essential requirements for wireless communications networks. Consequently, how to efficiently guarantee QoS for video broadcast attracts more and more research attention. However, the unstable wireless environments and the popular layer structured video signals impose a great deal of challenges in delay QoS provisionings. Due to the highly varying wireless channels, the deterministic delay QoS requirements are usually hard to guarantee. As a result, statistical delay QoS guarantees, in terms of effective bandwidth or capacity and queue-length-bound or delay-bound violation probabilities, have been proposed and demonstrated as the powerful way to characterize delay QoS provisioning for wireless traffics. Besides QOS, many energy-efficiency techniques for wireless networks can be found in the literature, which include lower-layers adaptation, optimization and end-users applications specifically designed to save energy. Thus energy-efficiency is becoming a key factor for the successful deployment of wireless networks. The development and validation of mechanisms for energy- efficient video broadcasting require the measurement of the energy consumption needed for video transmission. This paper presents an optimal energy efficient video transmission for cooperative wireless networks.***

Keywords: Bandwidth, Flow selection, QOS**,** Spanning tree.

1. Introduction

Energy consumption by mobile stations during downloading multimedia file is more. To maintain quality of service (QoS) in terms of throughput, delay, mobile terminal (MT) battery consumption various multimedia applications require high data rate [1]. Energy consumption in battery-operated mobile devices should be reduced for the development of the next generation heterogeneous wireless communications systems [2]. The presence of mobile stations with multiple wireless network interfaces has opened up a new area of research that tries to overcome the limitations of a single wireless technology by allowing collaboration among multiple MTs over alternative wireless technologies [1]. Distribution and cooperation is expected to be an solution to save power consumption of energy by mobile terminal and to increase data rate and throughput.

Distribution means to divide the video file into number of parts and distribute it amongst various mobile terminal. Co operation is the sharing of downloaded video file with the other interested mobile terminal which lies within the reachable area. Cooperation among mobile devices in wireless network environment can provide performance gain in terms of increase in the network throughput, extending the network coverage, decreasing the end-user communication cost and decreasing the energy consumption [2]. In this work, we develop optimized resource allocation and flow selection schemes that can provide end-to-end statistical delay bounds and minimize energy consumption for video distribution over cooperative wireless networks. The cooperative content distribution problem can be subdivided into two parts: The first part is a continuous component that involves finding the optimal allocation of time slots for all multicast transmissions along all paths of a given network flow. The second part is a combinatorial component that involves selecting the flow that minimizes energy consumption among all other flows in the network independently for each video frame.

2. Related Work

This section presents the most relevant related work on energy-efficient video transmission over wireless networks. In [3], the authors have performed a study of energy- eficient video transmission over a wireless link, by controlling the parameters associated with the physical and link layers. The results showed energy savings of around 38 percent for a CDMA system supporting six users. However, the assessment was fully based on simulations, which does not accurately represent the real systems. Other simulation based works have proposed energy-efficiency approaches for video broadcasting based on scalable video coding features, using content-aware rate control techniques [4]. In [5], the authors have employed cross-layer techniques to improve multimedia application quality, while minimizing battery energy consumption. The proposed cross-layer solution was validated in a test- bed using a digital oscilloscope for the energy related assessment, but it has not studied the impact of the approach in the end-user perceived quality. The evolution of the video quality metrics has shown the importance of an accurate assessment of end-user QoE [6].

Many works have studied the impact of broadcasting video within different network conditions in the QoE perceived by the end-user, but without any focus on energy consumption [7] [8]. In [9], the authors have assessed the energy consumption of generic cloud computing applications in an empirical test- bed, by analyzing the impact of packet rate and packet size in the end-user system. However, the methodology presented does not have the capability to measure video power consumption, neither the quality of experience perceived by the end-user.

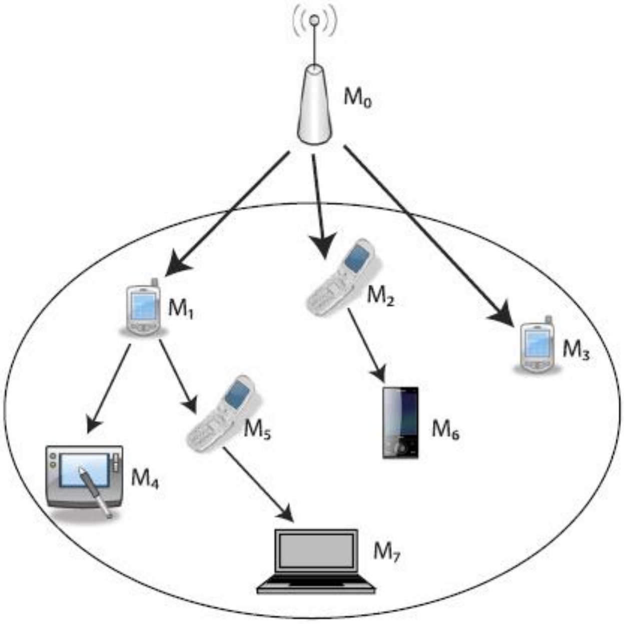

Figure 1: Example Network with a Fixed Network Flow

3. Proposed Work

3.1 Cooperative Network Model

The proposed system model consists of a base station, denoted by M0, and K mobile stations- M1, M2 . . ., MK which are capable of transmitting, receiving and relaying a scalable video bit- stream. The base station is responsible for distributing the same multilayer video stream to the mobile stations over wireless fading channels. Figure 1 shows an example network with seven mobile stations and a fixed network flow used to explain the system model. This network flow consists of four distinct paths leading to M4, M7, M6, and M3 and traversing all mobile stations. The video stream generated by the scalable video codec consists of "L" video layers. Each layer maintains a separate queue at each of the node and has specific QoS requirements according to its relevance in the decoding process.

The time frame "T" is defined as the difference between the playback time of two video frames at the receiver, i.e., the reciprocal of the video frame rate. Within this duration "T", the video frame contents corresponding to the "L" layers should be transmitted as per the construction of flow Fn to all K receivers to avoid playback buffer starvation. Figure 2 shows the time frame structure corresponding to the fixed network flow in Figure 1 for explanation purposes.

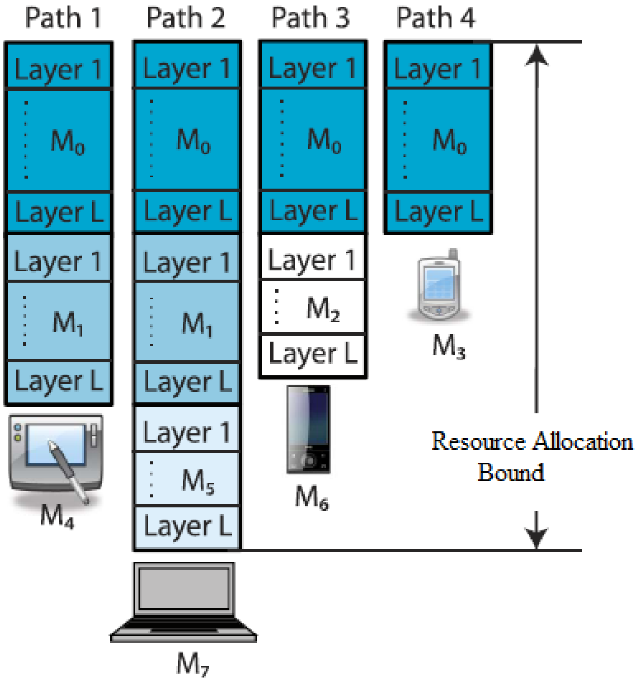

Figure 2: Time Frame Structure of the Network Flow

3.2 Queueing Network Model for Multi hop Video Transmission

A separate queue is maintained for each video frame layer at each node. The arrival process at the base station is denoted $\{A_{0,l}\}_{l=1}^{L}$ and is determined by the scalable codec parameters and the video content. Given this arrival process and the instantaneous signal- to- noise ratios (SNRs), we are interested in adaptively configuring the service processes such that the following condition is satisfied:

$$\Pr\left\{ \sum_{k\in\mathcal{P}_i^n} D_{k,l}^n > D_{\mathrm{th}} \right\} \leq P_{\mathrm{th}}\ \forall l, i$$

Where $D_{k,l}^n$ is the queuing delay at node k for layer *"l"* if flow Fn is used, Dth is the end-to-end statistical delaybound, Pth is the target delay-bound violation probability, P_i^n is the set of nodes along the ith path of flow Fn.

3.3 Effective Bandwidth/ Capacity Model

The effective capacity channel model captures a generalized link-level capacity notion of the fading channel by using wireless channels in terms of functions that can be easily mapped to link-level QoS metrics, such as delay-bound violation probability. Thus, it is a convenient tool for designing various QoS provisioning mechanisms. The effective capacity can be expressed as follows:

$$C^{n}_{k,l}(\theta_l) = -\frac{1}{\theta_l}\log\left(\mathbb{E}\{e^{-\theta_l C^{n}_{k,l}}\}\right)$$

The target QoS exponent "θ_l" for a given layer *l* should be the same for all transmissions to guarantee the same level of quality over the entire path. To provide the QoS guarantee "θ_l" for the *l*th video layer, the effective capacity on the kth link should be equal to the effective bandwidth.

3.4 Combinatorial Encoding of Network Flows

Now we provide a methodology to count and enumerate all possible network flows. Since we define a network flow as a directed acyclic graph (DAG), we deduce that there is a one-to- one correspondence between the set of network flows and the set of spanning trees for the given network graph. Given a spanning tree, we can obtain the acyclic graph by starting at the base station and assigning unicast and multicast directed links for selected edges such that all nodes are covered. For our network of one base station and "K" mobile stations, we obtain the number of network flows as

$$N = (K+1)^{K-1}$$

3.5 Energy Efficient Resource Allocation

Now we propose a distributed approach to implement the resource allocation procedure above where we assume that each node knows only its own transmit rate Rk(γ) transmit power Pk,t, and its set of multicast nodes Mn . Additionally, to avoid added complexity, nodes are only allowed to send feedback to only their direct upstream node. Distributed fashion describes starting from the leaf nodes, each node Mk sums the component it receives from its downstream nodes, add and then send the incremental value to its upstream node. The base station can linearly transform the received incremental information to obtain using knowledge of its multicast tree and transmit rate. On each path starting from the leaf node, each node Mk adds to the incremental value it receives and then sends it to its upstream node until it reaches the base station which scales it by R0 performed at the base station with the knowledge of transmission rate for each path, so that each node computes its resource allocation and transmits accordingly. Each node knows the rate at which it receives from its upstream node "Mk0" and its own transmit rate. In addition the receiver can easily finds the resource allocation of its upstream node by sensing the time it takes to receive all the video layers. Thus, Mk allocates resources for its transmission according to an optimal allocation of nodes.

3.6 Optimal Flow selection

In this section, we propose two approximation algorithms to reduce the complexity involved in choosing the optimal flow for a given fading state. The objective of the proposed algorithms is to avoid the search process through the exponential number of possible tree structures.

Minimum Spanning Tree Flow Selection Algorithm:

The minimum spanning tree flow selection algorithm uses negated ratios as link- weights on the complete network graph, and finds the minimum spanning tree using these weights. The algorithm is as follows:

Step 1: Given the fading state

$$\gamma[j] \triangleq \{\gamma_{k,k'}[j]\}_{k=0,k'=1}^{K\quad K}$$

construct the complete network graph with edge weights

$$\gamma_{k,k'}[j]$$

on the link between nodes M_K and M_{K^1} .

Step 2: Now use Prim's algorithm (Figure 3) to obtain the minimum spanning tree. This algorithm continuously increases the size of a tree, one edge at a time, starting with a tree consisting of a single vertex, until it spans all vertices.

Input: A non-empty connected weighted graph with vertices V and edges E (the weights can be negative).

Initialize: V_{new} = {x}, where x is an arbitrary node (starting point) fromV, E_{new} = {}

Repeat until V_{new} = V:

Choose an edge (u, v) with minimal weight such that u is inV_{new} and v is not (if there are multiple edges with the same weight, any of them may be picked)

Add v to V_{new}, and (u, v) to E_{new}

Output: V_{new} and E_{new} describe a minimal spanning tree

Figure 3: Prim's Algorithm

Step 3: The spanning tree is mapped to the corresponding directed acyclic graph (DAG) representing the network flow, and wireless resources are allocated on that flow to minimize total energy consumption.

Step 4: The chosen flow under this strategy maximizes the sum ratios over the network links, or equivalently the sum rate because the shannon rate is a concave function of the SNR.

Dominant Set Flow Selection Algorithm:

The dominant set flow selection algorithm is based on the observation that most of the network flows can only be optimal for a small percentage of the fading states corresponding to extreme instantaneous SNRs on the network links. For instance, if mobile station M1 lies between the base station and mobile station M2, it is very unlikely that the transmission to M1 through M2 is more energy efficient than the transmission toM2 throughM1.We thus attempt to reduce the number of candidates by taking into account the network flows that collectively correspond to a very large percentage of the fading states. We refer to this set of network flows called as the dominant set. Since we employ a block fading model, the flows that are best in a percentage p of the fading states are also optimal in a percentage p of the video frames for an asymptotically large number of video frames. Thus, we can estimate the dominant set flow using an offline simulation of the brute- force algorithm.

4. Conclusions

The problem of resource allocation with statistical QoS guarantees and optimized energy consumption over cooperative multi hop networks with general topologies has not been tackled yet in the literature. In this paper, we develop optimized resource allocation and flow selection schemes that can provide end-to-end statistical delay bounds and minimize energy consumption for video distribution over cooperative wireless networks. We model the queuing behavior of the cooperative wireless network according to the effective capacity link layer model. Moreover, we propose two approximation schemes to solve the flow selection problem which involves selecting the optimal flow in terms of minimizing energy consumption. The first algorithm, called minimum spanning tree flow selection, uses negated signal-to-noise ratios (SNRs) as link- weights on the complete network graph, finds the minimum spanning tree using those weights to maximize the sum rate, and then performs optimal resource allocation on the flow corresponding to the obtained tree structure. The second algorithm, called dominant set flow selection, maintains a set of dominant flows that are optimal for a potentially large percentage of channel states under a certain network topology and performs flow selection on that dominant set. The solution ensures reliable delivery of the video files to all requesting mobile terminals.

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