SV-BCMCS: Scalable Video Multicast in Hybrid 3G/Ad-hoc Networks

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***Abstract*—Mobile video broadcasting service, or mobile TV, is a promising application for 3G wireless network operators. Most existing solutions for video broadcast/multicast services in 3G networks employ a single transmission rate to cover all viewers. The system-wide video quality of the cell is therefore throttled by a few viewers close to the boundary, and is far from reaching the social-optimum allowed by the radio resources available at the base station. In this paper, we propose a novel scalable video broadcast/multicast solution, SV-BCMCS, that efficiently integrates scalable video coding, 3G broadcast and ad-hoc forwarding to balance the system-wide and worst-case video quality of all viewers in a 3G cell. We study the optimal resource allocation problem in SV-BCMCS and develop practical helper discovery and relay routing algorithms. Through analysis and extensive OPNET simulations, we demonstrate that SV-BCMCS can significantly improve the system-wide video quality at the price of slight quality degradation of a few viewers close to the boundary.**

***Index Terms*—Scalable Video Coding, Resource Allocation, Ad-hoc Video Relay,**

I. INTRODUCTION

User demands for content-rich multimedia are driving much of the innovation in wireline and wireless networks. Mobile video broadcasting service, or mobile TV, is expected to become a popular application for 3G network operators. The service is currently operational, mainly in the unicast mode, with individual viewers assigned to dedicated radio channels. However, a unicast-based solution is not scalable. A broadcast/multicast service over cellular networks is a more efficient solution with the benefits of low infrastructure cost, simplicity in integration with existing voice/data services, and strong interactivity support. Thus, it is a significant part of 3G cellular service. For instance, Broadcast/Multicast Services (BCMCS) [1], [2] is a standard in the Third Generation Partnership Project 2 (3GPP2) [3] for providing broadcast/-multicast service in the CDMA2000 setting. Most existing BCMCS solutions employ a single transmission rate to cover all viewers, regardless of their locations in the cell. Such a design is sub-optimal. Viewers close to the base-station are significantly "slowed down" by viewers close to the cell boundary. The system-wide perceived video quality is far from reaching the social-optimum.

In this paper, we propose a novel scalable video broadcast/multicast solution, **SV-BCMCS***, that efficiently integrates scalable video coding, 3G broadcast and ad-hoc forwarding to achieve the optimal trade-off between the system-wide and worst-case video quality perceived by all viewers in the cell.* In our solution, video is encoded into one base layer and multiple enhancement layers using Scalable Video Coding (SVC) [4]. Different layers are broadcast at different rates to cover viewers at different ranges. To provide the basic video service to all viewers, the base layer is always broadcast to the entire cell. The transmission ranges of the enhancement layers are optimally allocated to maximize the system-wide video quality given the location of the viewers and radio resources available at the base station. In addition, we allow viewers to forward enhancement layers to each other using short-hop and high-rate ad-hoc connections. Through analysis and simulations, we show that SV-BCMCS can increase the average received video rate by 76.85% at the price of a slight decrease of the video rate of a few users close to the boundary. Specifically, the contribution of this paper is three-fold:

1) We study the optimal resource allocation problem for scalable video multicast in 3G networks. We show that the system-wide video quality can be significantly increased by jointly assigning the transmission ranges for enhancement layers.
2) For ad-hoc video forwarding, we design efficient helper discovery scheme for viewers to obtain additional enhancement layers from their ad-hoc neighbors a few hops away. Also a multi-hop relay routing scheme is designed to exploit the broadcast nature of ad-hoc transmissions and eliminate redundant video relays from helpers to their receivers.
3) We conducted extensive simulations in OPNET. Systematical simulations demonstrate that SV-BCMCS can significantly improve video quality perceived by viewers in practical 3G/ad-hoc hybrid networks.

The rest of the paper is organized as follows. Related work is described in Section II. The SV-BCMCS architecture is first introduced in Section III. We then formulate the optimal layered video multicast problem and solve it. Finally, the helper discovery and multiple-hop relay routing algorithms are developed. Extensive OPNET simulation results are shown and discussed in Section IV. The paper is concluded in Section V.

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II. Related Work

Using ad-hoc links to help data transmissions in 3G networks has been studied by several research groups in the past. In [5], a Unified Cellular and Ad-hoc Network (UCAN) architecture for enhancing cell throughput has been proposed. Clients with poor channel quality select clients with better channel quality as their proxies. The proxy node then forwards the packet sent from the base station to the client through an ad-hoc network composed of other mobile clients and IEEE 802.11 wireless links. In [6], two categories of approaches are proposed to improve the performance of ad-hoc network in cellular system, one is to leverage the assistance from the base station, and the other is to leverage the relaying capability of multihomed hosts.

While the above articles are focused on the unicast data transmission in cellular networks, ad-hoc transmission can be also employed to improve the performance of 3G BCMCS. Based on the UCAN, Park and Kasera [7] developed a new proxy discovery algorithm for the cellular multicast receivers. The effect of ad-hoc path interference is taken into consideration. ICAM [8] developed a close-to-optimal algorithm for the construction of the multicast forest in the integrated cellular and ad-hoc network. Sinkar et al. [9] proposed a novel method to provide QoS support by using an ad-hoc assistant network to recover the loss of multicast data in the cellular network. However, the aforementioned works did not make use of SVC coded streams, which allow cellular operators to flexibly select the operating point so as to strike the right balance between the system-wide aggregate performance and individual users' perceived video quality.

Layered video multicasting combined with adaptive modulation and coding to maximize the video quality in an infrastructure based wireless network is studied in [10]–[12]. They differ in the way of formulating the optimal resource allocation problem. However, none of them takes the advantage of ad-hoc assistant network and analyzes the problem in the hybrid network context as we do.

III. Scalable Video Broadcast/Multicast Service (SV-BCMCS) over a Hybrid Network

In this section, we start with the introduction of the SV-BCMCS architecture. We then formulate and solve the optimal resource allocation problem for the base station to broadcast scalable video with the help of an ad-hoc network. Finally, we develop the helper discovery and layered video relay routing algorithms to explore the performance improvement introduced by ad-hoc connections between viewers.

A. System Architecture

In SV-BCMCS, through SVC coding, video is encoded into one base layer and multiple enhancement layers. Viewers who receive the base layer can view the video with the minimum quality. The video quality improves as the number of received layers increases. An enhancement layer can be decoded if and only if all enhancement layers below it are received. The multicast radio channel of the base station is divided into multiple sub-channels. Different layers of video are broadcast using different sub-channels with different coverage ranges. To maintain the minimum quality for all viewers, the base layer is always broadcast using a sub-channel to cover the entire cell. To address the decoding dependency of upper layers on lower layers, the broadcast range of lower layers cannot be shorter than that of higher layers.

Figure 1 depicts the system architecture of SV-BCMCS with eleven multicast users and three layers of SVC video, $L1$, $L2$, and $L3$. The base station broadcasts three layers using three sub-channels with their respective coverage areas. User a is in the coverage of $L3$ and user b is in the coverage of $L2$. User a relays $L3$ to user b, who then relays $L3$ to users c and d. Meanwhile, user b relays $L2$ to users c and d. Effectively, all four users a, b, c, and d receive all three layers through the combinations of base station broadcast and ad-hoc relays.

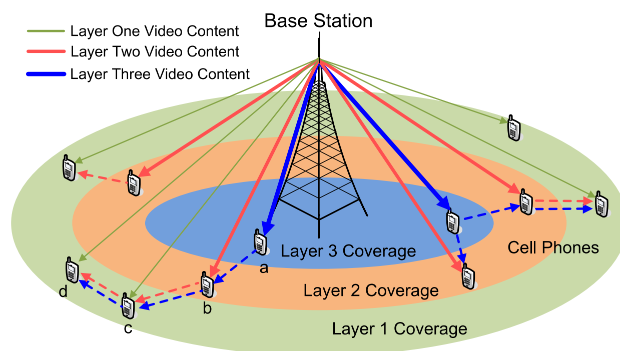


Fig. 1. Architecture of SV-BCMCS over a hybrid network (assuming three layers of video content).

The key design questions of the SV-BCMCS architecture are:

1) How to allocate the radio resources among sub-channels (layers) to strike the right balance between system-wide and worst-case video quality among all users?
2) How to design an efficient helper discovery and relay routing protocol to maximize the gain of ad-hoc video forwarding?

We examine these questions through analysis and simulations in the following sections. The key notation used in this paper are shown in Table I.

B. Optimal Resouce Allocation in Layered Video Broadcast

Our objective of radio resource allocation is to maximize the aggregate user perceived video quality while maintaining the minimum quality for all users. Various theoretical and empirical studies [4], [13] show that the higher the received video rate, the higher the Peak Signal-to-Noise Ratio (PSNR), which is widely used as an indicator of video quality. Their relationship is dependent on the specific video coding schemes and is not the focus of this paper. In the following, unless otherwise noted, we use the received data rate as the video quality metric. However our analysis and algorithms can be easily adapted to using other general utility functions [13].

Assume there are L video layers, and the video rate of each

TABLE I
NOTATION USED IN THIS PAPER

r_i	selected transmission rate (PHY mode) for layer i video content
p_i	allocated fraction of channel for tansmission of layer i video content in 3G system
n_i	number of multicast users that can receive layer i video/content in 3G domain
R_i	encoding rate of an individual layer i.
L	total number of layers
N	total number of multicast users in the 3G domain
Φ	set of all possible transmission rates (or PHY modes)
U	aggregate data rate (utility) of users in the 3G domain

layer is a constant R_i, $1 \leq i \leq L$. The broadcast channel is divided into L sub-channels through time-division multiplexing. Each sub-channel can operate at one of the available BCMCS PHY modes. Each PHY mode has a constant data transmission rate. Layer i is transmitted using sub-channel i. Let p_i be the time fraction allocated to sub-channel i, and r_i be the actual transmission rate, or the PHY mode, employed by sub-channel i. In practice, to support the video rate of layer i, we should have $r_i * p_i \geq R_i$. In our formulation, we let $p_i = \frac{R_i}{r_i}$, and the summation of the time fractions $\sum_{i=1}^{L} p_i \leq 1$.

Suppose n_i multicast users can correctly receive layer i video/content in SV-BCMCS, then $n_i - n_{i-1}$ users, $1 \leq i < L$, receive exactly i layers of video/content, and n_L users receive all L layers. The aggregate data rate for all users is:

$$\begin{aligned} U &= (n_1 - n_2) \cdot R_1 + \cdots + (n_j - n_{j+1}) \cdot \sum_{i=1}^{j} R_i \\ &\quad + \cdots + n_L \cdot \sum_{i=1}^{L} R_i \\ &= \sum_{i=1}^{L} n_i \cdot R_i. \end{aligned} \tag{1}$$

For a fixed total number of multicast users N in the 3G domain, maximizing the average data rate of multicast users is the same as maximizing the aggregate data rate U in (1). Moreover, for a series of given video/content rates R_i, equation (1) indicates that it is only necessary to maximize the summation of all $n_i R_i$, $1 \leq i \leq L$.

Next, the computation of n_i is discussed. The value of n_i is determined by the transmission rate r_i for sub-channel i. Due to path loss, fading, and user mobility, n_i is generally a monotonically decreasing function of r_i. The higher the transmission rate of the base station, the fewer the multicast users that can achieve the receiving SNR requirement, then correctly receive the data. Thus, we can define $n_i = f(r_i)$.

It can be assumed that path loss is the same at a given transmit-receive distance. Using the free-space path loss model, for each transmission rate r_i, the maximum coverage distance d_i can be derived based on the BER and SNR requirements for the PHY mode. Without ad-hoc assistant network, for a given user location distribution, n_i is the number of users falling into the disc centered at the base station with radius d_i.

In SV-BCMCS, due to the aid of ad-hoc network, with the same transmission rate r_i, the base station can reach a larger number of users $\tilde{f}(r_i) \geq f(r_i)$, where $\tilde{f}(r_i)$ denotes the number of users that can receive layer i with ad-hoc wireless relay turned on. In the system design, the base station needs to know exactly which node is getting data from which helper. This is done in the helper discovery protocol introduced next in Section III-C. Then base station can count n_i based on the information gathered through the protocol.

The optimal radio resource allocation problem can be formulated as the following utility maximization problem:

$$\max_{\{r_i\}} \quad U = \sum_{i=1}^{L} \tilde{f}(r_i) R_i, \tag{2}$$

subject to:

$$r_i \leq r_j \qquad i \leq j \text{ and } i, j = 1, 2, \cdots L, \tag{3}$$

$$\sum_{i=1}^{L} (\frac{R_i}{r_i}) \leq 1, \tag{4}$$

$$\tilde{f}(r_1) = N, \tag{5}$$

$$r_i \in \Phi. \tag{6}$$

The objective is to find a set of transmission rates r_i for each layer, to maximize the average data rate. For the constraint given by (6), Φ is the set of possible transmission rates (or PHY modes). The constraint given by (3) ensures that the coverage of lower layers is larger than that of the higher layers. Constraint (4) guarantees that the sum of the sub-channel time fractions p_i is no greater than one. Constraint (5) ensures that the base layer covers the whole cell to provide basic video service to all the users. Note that the traditional broadcast/multicast with one single stream becomes a special case of the above optimization problem with $L = 1$.

We have also designed a dynamic programming algorithm to solve the optimization problem formulated above. The complexity of the algorithm is $O(L^2 K^2)$, where K is an integer for rescaling the sub-channel allocation fractions p_i. K can be 10^n if all p_i can be expressed using at most n significant digits. Given the page limitation, the details of the algorithm are compiled in [14].

C. Ad-hoc Video Relay: Helper Discovery and Relay Routing

In a pure SV-BCMCS solution, users closer to the base station will receive more enhancement layers from the base station. They can forward those layers to users further away from the base station through ad-hoc links. Ad-hoc video relays are done in two steps: 1) each user finds a helper in its ad-hoc neighborhood to download additional enhancement layers; 2) helpers merge download requests from their clients and forward enhancement layers through local broadcast.

1) Greedy Helper Discovery Protocol: We design a greedy protocol for users to find helpers. A greedy helper discovery protocol in the 3G and ad-hoc hybrid network was first presented in [5]. In that paper every node of the multicast group maintains a list of its neighbors, containing their IDs and the average 3G downlink data rates within a time window. Users periodically broadcast their IDs and downlink data rates to their neighbors. Each user greedily selects a neighbor with the highest downlink rate as its helper. Whenever a node wants to download data from the base station, it initiates helper discovery by unicasting a request message to its helper. Then the helper will forward this message to its own helper, so on and so forth, until the ad-hoc hop limit is reached or a node with local maximum data rate is found. The ad-hoc hop limit is set by a parameter Time-To-Live (TTL) in this paper. The helpers will forward the data in the reverse direction of helper discovery to the requesting node.

We employ a similar greedy helper discovery mechanism. But unlike the case considered in [5], the locations of helpers will change the resource allocation strategy of the base station in SV-BCMCS. In our scheme, the last node in the path sends the final request message to the base station. Upon receiving this message, the base station updates the 3G data rate information of all the nodes along the path as the last node's 3G rate. After that, the base station might resolve the coverage function as $\tilde{f}(r_i) = \{\text{Number of nodes with updated 3G rate above } r_i\}$. The optimal broadcast strategy can then be calculated by solving the optimization problem defined in (2).

Moreover, to facilitate efficient relay routing, a node also needs to keep information about the relay requests routed through itself. The last node in the path also sends the final request message to the initiating node along the ad-hoc path.

The whole process is shown in Figure 2. User C attempts to find a helper within two hops to improve its video quality. Its request goes through B to A. E and F are ignored by C and B, since they are not the neighbor with highest 3G rate. To this end, User A knows where user C is located by the reverse route of the path that user C followed to find user A. User A sends a status message to the base station to indicate that user A will act as user C's helper using the relay path along user B. Meanwhile, User A also sends the final request message(confirmation message) back to user C confirming that user A will act as its helper.

2) SV-BCMCS Relay Routing Protocol: The SV-BCMCS routing protocol executes after the greedy helper selection protocol and the optimal radio resource allocation. Assuming optimal radio resource allocation has been performed, the base station decides to transmit the L layers with different rates $r_1, r_2, \cdots, r_L$. It will broadcast this information to every node in the cell. Moreover, in the greedy helper discovery phase, each node obtains the information for all the relay paths to which it belongs by the confirmation message. The major goal of the relay routing protocol is to maximally exploit the broadcast nature of ad-hoc transmissions and merge multiple relay requests for the same layer on a common helper.

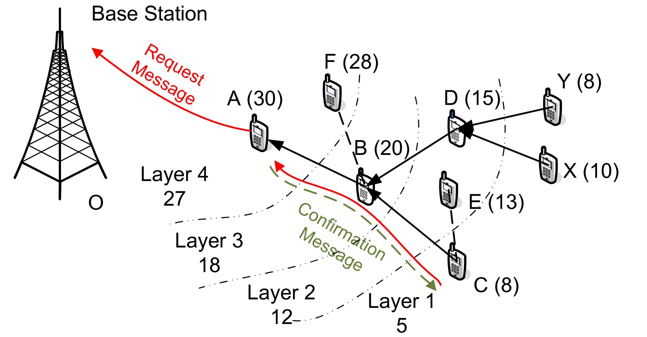


Fig. 2. Greedy Helper Discovery Protocol and Routing Protocol. The numbers in parenthesis are the average 3G rates for each node. The dashed line indicates the ad-hoc neighborhood. The straight solid line is the ad-hoc path with the arrow pointing to the helper. For routing protocol, dashed-dotted lines represent the coverage area of each layer. 27, 18, 12 and 5 are the physical transmission rates for layers 4, 3, 2 and 1.

Essentially, each helper needs to determine which received layers will be forwarded to its requesting neighbors. For each node n, the forwarding decision will be calculated as shown in Algorithm 1. Typically, the average number of neighbors of a node is small. Thus, the complexity of the algorithm is low.

Algorithm 1 Forwarding Algorithm in SV-BCMCS Routing Protocol for Node n

$\mathcal{N}$ ={ all node k that uses n as one-hop helper }
for $k \in \mathcal{N}$ **do**
    Find the highest layer l_k that k can directly receive from the base station
    Find the highest layer L_k that k can expect from any potential helper
end for
$l_{min} = \min\{l_k, k \in \mathcal{N}\}$
$L_{max} = \max\{L_k, k \in \mathcal{N}\}$
node n broadcasts the packets between layer $l_{min} + 1$ to L_{max} to its one-hop neighbors.

Each node receives packets that satisfy two conditions: (i) the packets are sent from its direct one-hop helper; (ii) the packets belong to a layer higher than the layer to which the node itself belongs to. Otherwise the node will discard the packets. That is, the node has no use for packets that are within the layer to which the node belongs, or from a lower layer than the layer to which it belongs.

A relay routing example is illustrated in Figure 2. Suppose $L = 4$ and maximal hop number is 2. For node B in the figure, nodes C and D use it as a direct one-hop helper. For D, $l_D = 2$ (it is the layer to which node D belongs) according to the figure, and within 2 hops, D's highest expected layer is $L_D = 4$. The highest expected layer is the highest layer which a node can expect to receive through its helpers while constrained by the maximum hop count. In the same way, we can derive, $l_C = 1$ and $L_C = 4$. Thus, for node B, $l_{min} = \min\{l_C, l_D\} = 1$ and $L_{max} = \max\{L_C, L_D\} = 4$. Therefore, node B will broadcast the packets in layers 2, 3 and 4. Node D, since it is in layer 2 and will hear the layers 2, 3 and 4 packets sent from node B, will receive packets in layers 3 and 4 only. Meanwhile, node C will receive all the packets in layers 2, 3 and 4.

IV. Performance Evaluation

In this section, the performance of SV-BCMCS is evaluated using OPNET based simulations. The performance of SV-BCMCS is compared with the performance of traditional 3G BCMCS under various scenarios. The impact of node density and number of relay hops is investigated, as well as the fairness issue. Results demonstrate that SV-BCMCS consistently out-performs BCMCS with or without the aid of ad-hoc data relay.

A. Simulation settings

SV-BCMCS is simulated using the wireless modules of OPNET modeler. It is assumed that all multicast users/nodes have two wireless interfaces: one supports a CDMA2000/BCMCS channel for 3G video service, and the other supports IEEE 802.11g for ad-hoc data relay. The data rate of the ad-hoc network is set to be 54 Mb/s, and the transmission power covers 100 meters. Since OPNET modeler does not have wireless modules with dual interfaces, the 3G downlink is simulated as if individual users generate their own 3G traffic according to the experimental data presented in [1], [15]. The free-space path loss model is adopted for 3G downlink channels, where the Path Loss Exponent (PLE) is set to be 3.52, and the received thermal noise power is set to be -100.2dBm. Eleven PHY data rates are supported according to the 3GPP2 specifications [16].

The 3G cell is considered to be a circle with a radius of 1000 meters, with a base station located in the center. It is assumed that 3G BCMCS supports a video streaming rate of 153.6 kb/s. According to [1], 153.6 kb/s can be supported in almost 100 percent of the coverage area using a Reed-Solomon error correction code. The transmission power of the 3G base station is set accordingly so that BCMCS can broadcast the video to the entire cell. The same base station transmission power is used in SV-BCMCS evaluations. Constant Bit Rate (CBR) video is used in the simulations with a packet size of 1024 bytes. A user's average received data rate is used as an indicator of the user's received video quality.

B. Stationary Scenarios

In stationary scenarios, a certain number of fixed nodes are uniformly distributed in the 3G cell. Regarding the relay delay, we try to mediate its adverse impact by limiting the number of ad-hoc relay hops (< 4 hops). The ad-hoc network has a high bandwidth of 54 Mb/s compared with the video rate (several hundred kb/s). With a small number of hops and high-rate ad-hoc connection, the delay is negligible. Meanwhile, mobile device can always delay the start of the video playback to accommodate the relay delay. The presented results are averages over ten random topologies. The 90% confidence interval is also determined for each simulation point.

TABLE II
Data Rate Comparison for Different Node Density (kb/s)

Node No.	Single Stream	SV-BCMCS without ad-hoc	SV-BCMCS with ad-hoc
100	153.6	210.24 (36.88%)	220.16 (43.33%)
200	153.6	211.53 (37.72%)	232.71 (51.50%)
300	153.6	206.11 (34.19%)	244.51 (59.18%)
400	153.6	209.11 (36.14%)	258.93 (68.55%)
500	153.6	204.68 (33.20%)	267.83 (74.35%)
600	153.6	207.35 (34.96%)	271.64 (76.85%)

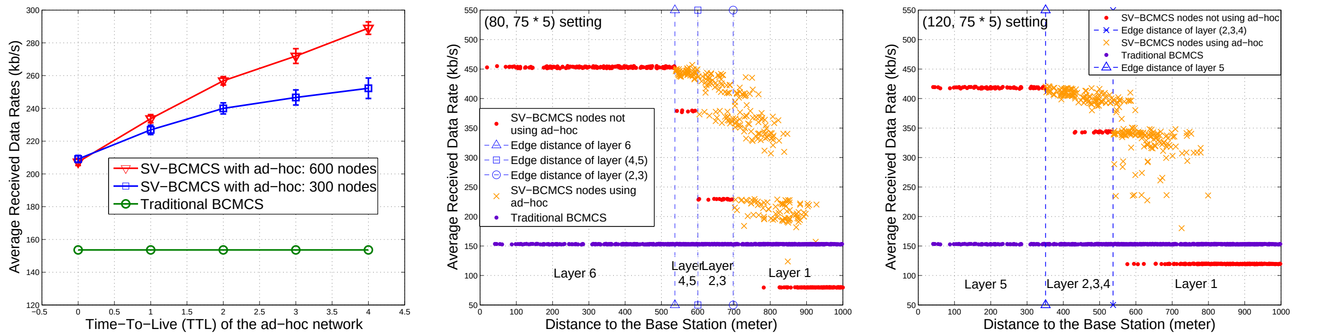
1) The Impact of Node Density: In this scenario, we fix the base layer rate to 100 kb/s and each enhancement layer rate to 64 kb/s, with the video consisting of one base layer and five enhancement layers. We use (100, 64 * 5) to represent this layered video stream and all the scenarios will use this setting, unless specified otherwise. The number of multicast nodes in the cell ranges from 100 to 600, to simulate a sparse to dense node distribution. "Traditional BCMCS" indicates the transmission of a 153.6 kb/s single layer video, covering the whole cell.

Table II lists the average data rates and the percentage gain for SV-BCMCS with/without ad-hoc network and different numbers of users. We can see from the table that the SV-BCMCS with (100, 64 * 5) setting provides up to a 76.85% average data rate gain compared to traditional BCMCS. Without ad-hoc, the optimal allocation in SV-BCMCS can support around a 36% improvement. The ad-hoc network delivers a larger performance gain when the node density increases. When the number of nodes is 100, it gives an 6.45% additional improvement, while when the node number is 600, the additional improvement reaches 41.89%.

2) The impact of number of relay hops (TTL): Figure 3(a) depicts the performance of SV-BCMCS under different TTLs. Here the impact of ad-hoc relay is examined in a practical setting - with a varying number of relay hops and in the presence of wireless interference. The experiments are done with the number of users set to be 300 and 600, respectively. They represent different node density levels. With TTL=1 and 300 users, the average received data rate is 47.71% higher than the rate supported in traditional BCMCS. The improvement percentage increases to 64.26% when the TTL reaches 4. Ad-hoc relay achieves better performance with more users in the cell. A higher user density leads to a larger probability of connecting to a helper with higher rate. With TTL values ranging from one to four in the 600 users scenario, the data rate improvement percentage rises from 52.17% to 88.16%, respectively. Note that with TTL=0, no ad-hoc relay is used. In this case, SV-BCMCS still out-performs BCMCS by 36.15%.

C. Fairness Issue

In SV-BCMCS, depending on a user's location, it may receive the same video at different quality levels by receiving a different number of video layers. In the worst case, a user may only receive the base layer, which is transmitted to the entire



(a) TTL impact: average received data rate.

(b) SV-BCMCS in (80, 75 * 5) setting

(c) SV-BCMCS in (120, 75 * 5) setting

Fig. 3. Fairness issue in SV-BCMCS. Optimal resource allocation significantly improves the system-wide video rate at the price of a small rate decrease for nodes close to the boundary; ad-hoc relays further increase the rate for all users, almost all users achieve a higher video rate than in the traditional BCMCS.

cell. SV-BCMCS allows users having better channel condition to receive better quality video, which is "fair" to some degree. The study of the right fairness metric, however, is outside the scope of this paper. Here we focus on the tradeoffs between the base layer rate and the overall improvement of user perceived video quality.

Figure 3(b) and 3(c) shows the average received data rate vs. the distance to the base station in SV-BCMCS. Six layers are used and the base layer rate is set to be 80 kb/s and 120 kb/s, respectively. The rates of enhancement layers are set to be 75 kb/s. There are 600 users in the cell. Vertical lines indicate the transmission ranges of different video layers. Note that several layers may be transmitted to cover the same range.

Each point in the figure represents one user. Clearly, more users in the small base rate case (base layer rate of 80 kb/s) are able to enjoy higher data rate ($>$ 153.6 kb/s) than in the large base rate case (base layer rate of 120 kb/s). When using less channel bandwidth to deliver a smaller rate base layer, enhancement layers are transmitted further. However, the users who only obtain the base layer perceive worse video quality in the small base rate case than in the large base layer rate case. With the aid of ad-hoc data relay, more users are able to receive higher data rate regardless of the base layer rate.

V. Conclusion

In this paper we present SV-BCMCS, a novel scalable video broadcast/multicast solution that efficiently integrates scalable video coding, 3G broadcast and ad-hoc forwarding. We formulate the resource allocation problem for scalable video multicast in a hybrid network whose optimal solution can be resolved by a dynamic programming algorithm. Efficient helper discovery and video forwarding schemes are designed for layered video/content dissemination through ad-hoc networks. Finally, OPNET simulations show that a practical SV-BCMCS increases the average received video rate by 76.85%, with the ad-hoc networks accounting for 41.89% improvement. The fairness issue is discussed and we demonstrate that SV-BCMCS can significantly improve the system-wide video quality, though a few viewers close to the boundary will have a slight rate degradation.

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