# Wireless Video Multicast in Tactical Environments

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*Abstract*— **There has been a tremendous increase in demand for real-time video applications over military networks. Multicast provides an efficient solution for simultaneous content delivery to a group of users. It is especially valuable for military applications, as it saves network resources by sharing the data streams across receivers. Even with ever increasing channel bandwidth and computation power, efficiently multicasting video over the tactical edge is still challenging due to factors such as higher packet loss ratio, bandwidth variations and the heterogeneity of the users. In this paper, we explore the use of omni-directional relays to improve the performance of wireless video multicast in tactical environments. We focus on assessing the trade-off between total relay energy, coverage area and video quality. The results provide achievable operational regions, which can serve as a reference and a starting point for system design.**

**Index Terms**: video transmission, omni-directional antennas, relays, wireless video multicast, tactical environment

## I. INTRODUCTION

The inherent broadcast nature of the wireless channel makes it an ideal medium for multicast applications in tactical environments. The key advantage of multicast lies in a significant reduction of communication costs in tactical networks, where the bandwidth of the wireless link is a scarce resource. By harnessing the efficiency of multicast, network resources can be conserved, thereby enabling the delivery of high fidelity content to strategic locations. As such, multicast serves as an attractive method for one-to-many content distribution in tactical networks. Potential military applications that could benefit from multicast distribution range from dissemination of situational awareness data to streaming video feeds from Unmanned Aerial Vehicles (UAV) to forward-deployed war fighters.

Even with the increase in both the bandwidth of wireless channels and the computational power of mobile devices, an efficient implementation of wireless video multicast still poses challenges due to high packet loss ratio, heterogeneity of the users, and channel variations. There are several studies discussing the recovery of packet losses in video multicast over wireless networks, e.g., [1], [2]. Heterogeneity among clients refers to each receiver having a different connection quality and power limitation. Scalable (layered) video coding is one approach to solve the heterogeneity problem. Several researchers have studied layered video multicast in infrastructure-based wireless networks, including [3]-[5]. Abdelmalek *et al.* [6] suggest a mechanism that gives the receiver dynamic ability to move from one multicast group to another

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based on the receiver capabilities and the network conditions, in order to improve the quality of the real-time media communication in a tactical environment. The capabilities and challenges of deploying a tactical WiMAX network is investigated in [7], where locality-based communication and tracking services, as well as the back-haul of video, imagery, and sensor data are discussed.

In our previous work, we integrated layered video coding with cooperative multi-hop transmission to enable efficient and robust video multicast in infrastructure-based wireless networks [8]. The basic idea behind the cooperative multicast system is that we divide all the receivers into two groups such that receivers in Group 1 have better average channel quality than Group 2, and we let the sender choose its transmission rate based on the average channel quality of Group 1. Then, selected receivers in Group 1 will relay the received information to Group 2 users. We considered omni-directional relay transmission, where each relay targets a subgroup of Group 2 users and transmits at a different time slot, and a Group 2 user only listens to its designated relay. We showed that cooperative multicast with omni-directional relays improves the multicast system performance by providing better quality links (both for sender and relay) and hence higher sustainable transmission rates. Furthermore, with the same sender transmission power, we achieved a larger coverage area.

In this paper, we consider cooperative multicast in a tactical environment where energy consumption is also critical. Therefore, we investigate the tradeoff between coverage area, video quality and total relay energy consumption via case studies on different design configurations.

This paper is organized as follows. We introduce the system model in Section II. We discuss the multicast performance in Section III. We formulate the optimum user partition in Section IV. Section V analyzes the obtained results. We conclude the paper in Section VI.

## II. SYSTEM MODEL

We consider tactical wireless video multicast in the context of infrastructure-based network. A typical scenario is to provide last-mile tactical service to forward deployed war fighters. We assume that a sender (a base station or access point) is multicasting video to uniformly distributed multicast receivers within its coverage area. Our system is based on a path loss model with a path loss exponent of $PLE$, which solely depends on the distance between a transmitter and its receiver. In other words, the receivers closer to the transmitter have better channel qualities and hence can support higher transmission rates than the far away receivers. While our results can also be extended to fading channels, in that case proper relay scheduling necessitates feedback about channel state information at the sender and the relays, and is beyond the scope of this paper.

We assume a dense network and divide all the receivers into two groups such that Group 1 receivers have better average channel quality than Group 2 receivers, and let the sender choose its modulation and channel coding schemes based on the average channel quality of Group 1. Selected receivers in Group 1 (to be called relays) will relay all or selected received packets from the sender to Group 2 receivers, with the modulation and channel coding schemes chosen based on the average channel quality of relays to Group 2 receivers. In general, Group 2 receivers can combine the received information from sender and the relays, but in this paper we consider the simple case where Group 2 receivers only listen to their designated relay. We show that even with such a multi-hop strategy, substantial gains in signal quality is achievable.

For the baseline direct transmission system, we assume that the sender uses a physical layer transmission rate of $R_d$ to cover users in a radius of $r_d$ with an access point power of $P_{AP}$. For the proposed multicast system with omni-directional antennas, we assume each relay targets a subgroup of Group 2 users and transmits at a different time slot, and that a Group

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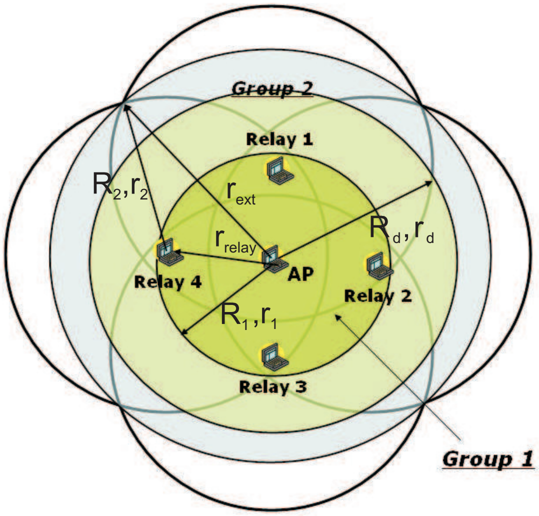

Fig. 1. System set-up

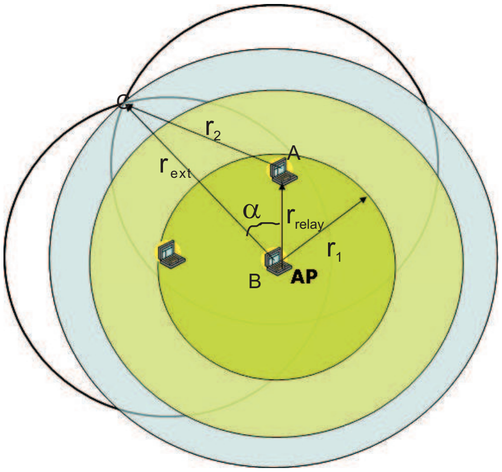

Fig. 2. Geometric model for the system

2 user only listens to its designated relay. In general, a user may move from one location (Group 1) to another (Group 2) at different times. Furthermore, we can choose different users in Group 1 to be relays at different times. The snapshot view of this network is illustrated in Figure 1. Here note that, both the sender-to-Group 1 receivers' links and relay-to-Group 2 receivers' links have better quality and hence higher sustainable transmission rates than a direct sender to Group 2 link. We assume that at the sustainable transmission rate, the packet loss is negligible. In Group 1, we assume that with an access point transmission power of $P_{AP}$, we can cover users within a radius of $r_1$ with a sustainable transmission rate of $R_1$. Similarly, in the second hop transmission, the relays transmit at a rate $R_2$, with a relay power of $P_{relay}$ and cover the users within a radius of $r_2$. We assume that the video data is sent in intervals of $T$ seconds, and the sender and the relays use $T_1$ and $T_2$ seconds for their transmission, respectively, such that $T = T_1 + NT_2$ where $N$ stands for the number of relays. With this setup, we cover an area of a radius $r_{ext}$ such that $r_{ext} > r_d$.

## III. MULTICAST PERFORMANCE

We consider three performance metrics: the received video quality, the coverage area of the multicast system, and the total energy consumption of the relays.

### A. Video Quality

With the set up described above, since each relay transmits at a different time slot for relay transmission, received video rates will be different from the transmission rate. We can express the received video rates for Group 1 and Group 2, $R_{v1}$ and $R_{v2}$, as

$$R_{v1}{=}\beta R_1 \tfrac{T_1}{T} \quad , \quad R_{v2} = \beta R_2 \tfrac{T_2}{T} \quad , \tag{1}$$

where $\beta$, $0 < \beta < 1$, is the effective payload ratio which is the ratio of the payload size to the actual packet size, which includes the overhead introduced by MAC and IP headers as well as the payload.

We define $Q_1(R_{v_1})$ as the quality of Group 1 receivers and $Q_2(R_{v_2})$ as the quality for Group 2 receivers. Note that $Q_1$ is a function of the received video rate, $R_{v_1}$, and for a given video file if we know $R_{v_1}$, we can compute $Q_1$. In this paper, we consider the case where we require all the receivers have the same video quality,

$$Q_1(R_{v_1}) = Q_2(R_{v_2}) \quad . \tag{2}$$

Here, note that for a given $R_1$, $R_2$ and $N$, we can find $T_1$ and $T_2$ and the corresponding $R_{v_1}$ and $R_{v_2}$, which satisfies the above equation.

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### B. Coverage Area

The extended coverage area of the system depends on the number of relays used. We assume that the relays are equally spaced at an angle $2\alpha = \frac{2\pi}{N}$, and at $r_{relay} = r_1$ in order to have the maximum coverage area. Then we calculate $r_{ext}$ using the cosine theorem on the triangle $ABC$ in Figure 2, by solving for the roots of the following second order equation,

$$r_{ext}^2 - 2r_1 \cos\alpha \; r_{ext} + r_1^2 - r_2^2 = 0 \quad . \tag{3}$$

### C. Total Energy Consumption of Relays

We express the energy consumption over each interval $T$ for the access point, $E_{AP}$, and each relay, $E_{relay}$, as

$$E_{AP} = P_{AP} T_1 \quad , \quad E_{relay} = P_{relay} T_2 \quad , \tag{4}$$

where $P_{AP}$ and $P_{relay}$ are the transmission powers for the access point and each relay, respectively. We consider the total energy consumption of relays which can be expressed as

$$E_{total} = N P_{relay} T_2 \quad . \tag{5}$$

## IV. USER PARTITION

The received signal power is related to the transmission power via the path loss model as

$$P_r = c\frac{P_t}{d^k} \quad , \tag{6}$$

where $d$ is the distance between source and destination, and $k$ is the path loss exponent. $P_t$ and $P_r$ are the transmitted and received powers, respectively. Here, the required $P_r$ depends on the acceptable packet loss rate. In general, it should be greater than some threshold value of the Bit Error Rate (BER). Hence, for given set of physical layer parameters, transmission power, path loss exponent and BER threshold, we can compute the coverage range for the corresponding transmission rates. Therefore, we express the coverage distances as a function of the transmission rate and the transmission power. We define $r_1(R_1, P_{AP})$ and $r_2(R_2, P_{relay})$ as the coverage ranges for Group 1 and Group 2, respectively. Similarly, $r_d(R_d, P_{AP})$ is the coverage range with direct transmission.

Note that, for a fixed relay power and transmission rate, as we reduce the number of relays, due to time scheduling, we increase the received video rate, and hence the quality of the video. However, if we decrease the number of relays too much, then we may not able to cover all the users in the coverage area of direct transmission. Therefore, there is a minimum number of relays, $N_{min}$, which cover all the users in direct transmission range. On the other hand, as we increase the number of relays we can cover a larger area while sacrificing video quality. Thus, if we increase the number of relays too much, we may not be able to provide a better video quality to the users than the direct transmission. Hence, there is a maximum number of relays, $N_{max}$, which guarantees that the quality of the video is equal to or greater than that with direct transmission.

In order to find the configuration with minimum number of relays which covers all the receivers within coverage range of direct transmission, $r_d$, we follow a geometric based approach. We define $r_{relay}$ as the distance between the base station and the relay, and $r_{ext}$ as the radius of the extended coverage area, as illustrated in Figure 2.

User partition is defined by $r_1$, $r_2$, and the separation angle $\alpha$ where the number of relays can be computed as $N = \frac{\pi}{\alpha}$. We define $\alpha_{max}$ as the maximum angle which satisfies the constraints below,

$$r_{relay} \leq r_1 \tag{7}$$

$$r_{ext} \geq r_d \quad . \tag{8}$$

More specifically, Equation (7) states that the relay is selected from the Group 1 receivers and Equation (8) states that all the receivers in Group 2 are guaranteed to be covered. The separation angle will be maximum (and hence the number of relays will be minimum) when $r_{relay} = r_1$ and $r_{ext} = r_d$. Applying the cosine theorem to the triangle, $ABC$, in Figure 2, we can compute $\alpha_{max}$ as

$$\alpha_{max} = \arccos\frac{r_1^2 + r_d^2 - r_2^2}{2r_1 r_d} \quad . \tag{9}$$

Here, note that $r_1(R_1, P_{AP})$ depends on the Group 1 transmission rate and the transmission power of access point. Similarly, $r_2(R_2, P_{relay})$ depends on the Group 2 transmission rate and the transmission power of relays. Finally, $r_d(R_d, P_{AP})$ depends on the rate of direct transmission and transmission power of the access point. Then, the minimum number of relays, $N_{min}$, that can cover all the users in direct transmission range, can be expressed as

$$N_{min} = \lceil \frac{2\pi}{2\alpha_{max}(R_1, R_2, R_d, P_{AP}, P_{relay})} \rceil \quad . \quad (10)$$

Note that $\alpha_{max}$, hence the minimum number of relays, is a function of transmission rates of Group 1 and Group 2, the transmission rate of direct transmission and the powers of the access point and the relays.

In order to find the maximum number of relays, $N_{max}$, we make sure that each user at least observes the same quality as direct transmission. Hence,

$$R_{v1} = R_{v2} = \beta \ R_d \quad . \qquad (11)$$

Using (1) and (11), the maximum number of relays, $N_{max}$, that guarantees at least the same quality as direct transmission, can be expressed as

$$N_{max} = (R_1R_2 - R_dR_2)/(R_1R_d). \qquad (12)$$

Note that, (12) only guarantees that the Group 1 and Group 2 users experience at least the same quality as direct transmission. However, we also need to find the user partition that guarantees all the users in the range of direct transmission to be covered. Recall that the user partition is determined by $r_1(R_1, P_{AP})$ and $r_2(R_2, P_{relay})$. Therefore, due to user partition, $N_{max}$ not only depends on the transmission rates, but also the access point power and the relay powers.

In light of the above formulation, we observe that the number of relays, and hence the received video rates and the extended coverage area, are determined by the access point power and the relay powers, as well as the transmission rates of direct transmission, Group 1 transmission and Group 2 transmission. Hence while designing a system, we need to find an optimum configuration considering the energy consumption, the coverage area, and the video quality.

## V. RESULTS

In this section, we illustrate the interplay among the total relay energy consumption, coverage area, and the video quality via case studies using different design configurations. In particular, we assume IEEE 802.11b based WLAN, though our approach and analysis can be applied to other channel models (such as Tactical Common Data Link (TCDL) and WiMax, based on their corresponding transmission rate - coverage range curve (similar to that in TABLE I). In order to obtain the direct transmission coverage range for each transmission rate of 802.11b, we use the following procedure. First, we simulate an IEEE 802.11b network and get the BER versus SNR (Signal-to-Noise Ratio) curves for all transmission modes of 802.11b for a fixed transmission power, $P_t$, where $P_t$ can be scaled. In our study, we assume a BER threshold of $10^{-4}$ and path loss exponent of $k = 4$, and obtain Table I. As a reference, we set the distance $r_d$ to be equal to 100m for the base rate of IEEE 802.11b ($1Mbps$) that can be supported with reference power, $P_t$, i.e., $P_{AP} = P_t$, $r_d = 100m$ when $R_d = 1Mbps$.

| **Sustainable Rate(Mbps)** | 11 | 5.5 | 2 | 1 |
|---|---|---|---|---|
| **Distance (m)** | 61 | 72 | 88 | 100 |

TABLE I

SUSTAINABLE RATES VS. DISTANCE WITH IEEE 802.11$b$, BASE RATE $1Mbps$. REFERENCE DISTANCE $100m$, REFERENCE TRANSMISSION POWER OF $P_t$.

Based on our prior measurements, we set $\beta = 0.25$, so at $1Mbps$ transmission, the payload rate is $250kbps$. We used an H.264/SVC codec and encoded 240 frames of the (352x288) Soccer video sequence whose rate distortion curve is given in Figure 3. We measure the video quality in terms of PSNR. The PSNR value of the video with direct transmission at the rate of $250kbps$ is 29.55 $dB$.

In Figure 4, we fix the coverage area to 100m and present the video quality for different total relay energies ranging from 0 to $1.6P_{AP}$ joules. For fixed total relay energy, we determine

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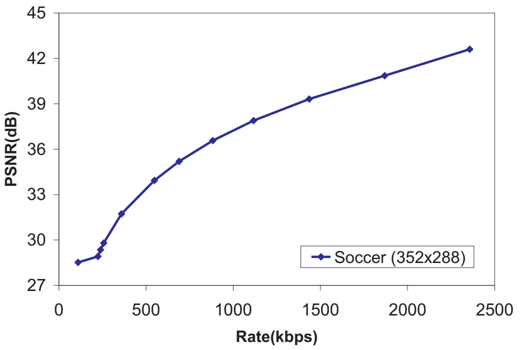

Fig. 3. Rate-distortion curve for Soccer video, obtained by using H.264/SVC encoder [9].

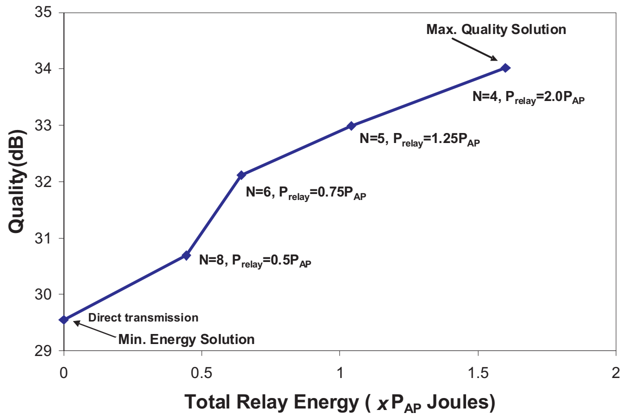

Fig. 4. Quality vs total relay energy spent for 1 second of video transmission for a fixed coverage area of 100m. The optimal transmission rates are $R_1 = R_2 = 11Mbps$.

the optimal $N$ and $P_{relay}$ that maximizes the quality. So each point in the figure is optimized for a given total relay energy. We vary the relay power by scaling the access point power, hence the total relay energy is computed in terms of the access point transmission power, $P_{AP}$. Furthermore, we assume $T = 1sec$ and compute the total relay energy spent for 1 second of video transmission. We observe that as we increase the energy spent by relays, we can cover all the users in the target coverage area of 100m with less relays due to a larger $r_2$, and hence the video quality also increases.

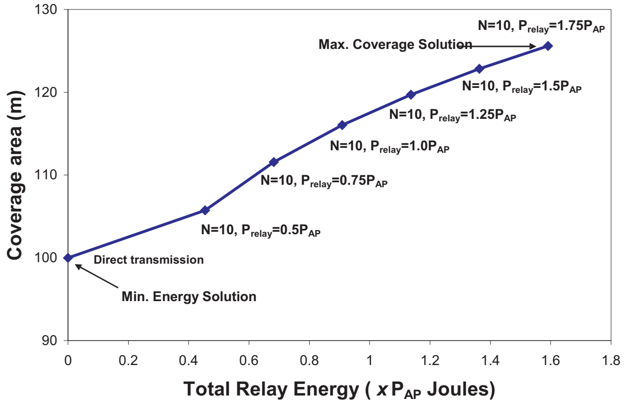

Fig. 5. Coverage vs total relay energy spent for 1 second of video transmission for a fixed quality of 29.55 dB at all users. The optimal transmission rates are $R_1 = R_2 = 11Mbps$.

In Figure 5, we fix the video quality to 29.55 $dB$ and present the coverage area for different total relay energies from 0 to 1.6$P_{AP}$ joules. Here, note that the number of relays is fixed since we fix the video quality to the quality of the direct transmission. We observe that as we increase the energy spent by relays, even when the number of relays is fixed, the coverage area also increases, due to a higher $r_2$.

In Figure 6, we fix the total relay energy, $E_{total} = 1.6P_{AP}$ joules, by varying the number of relays, $N$, and the relay power, $P_{relay}$. We present the video quality for different coverage areas. We observe that we need more relays to increase the coverage area and as we increase the coverage area, the video quality decreases. Note that the maximum coverage solution has $N_{max} = 10$ relays and it covers an area of radius 126m where all the users experience the same quality with direct transmission. If we increase the coverage area beyond 126m, since we need more relays than $N_{max}$, the users will experience worse quality than the direct transmission.

## VI. CONCLUSION

In this paper, we address tactical wireless video multicast in the context of an infrastructure-based network. We determine the user partition and transmission time scheduling that can optimize a multicast performance criterion. We show the trade-off between the relay energy consumption, coverage area, and the video quality via case studies with different

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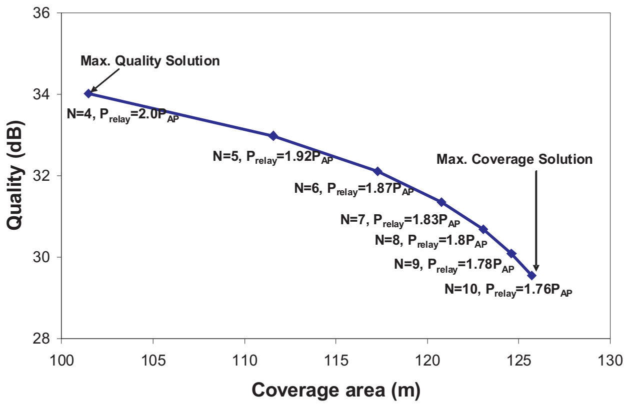

Fig. 6. Quality vs coverage area for a fixed total relay energy, $E_{total} = 1.6P_{AP}$. The optimal transmission rates are $R_1 = R_2 = 11Mbps$.

design configurations. We argue that wireless video multicast using relays improves the multicast system performance by providing better quality links (both for sender and relay) and hence higher sustainable transmission rates.

In this paper, we assume the users are uniformly and densely distributed in the coverage region of the AP and the channel condition is only affected by path loss. This enables us to perform optimum relay selection and compute the maximum achievable performance with omni-directional relay transmission. In a realistic environment, the user distribution may not be uniform and is likely to change over time. Furthermore, channel conditions are affected by both path loss and fading. How to obtain a good estimate of the channel conditions of all receivers through some efficient feedback mechanism and how to dynamically adapt the user partition based on such estimates are both challenging problems. These are subjects of our ongoing research.

This paper only considers omni-directional relay transmission where the relays cannot transmit simultaneously in time which reduces the system efficiency. To circumvent this problem, an on-going work is to explore the use of directional antennas where we can achieve efficient spatial reuse [10]. Additionally, directional transmission would increase the signal energy towards the direction of the receiver resulting in a further increase in the coverage area.

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