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MANET: Energy-Spectrum Efficiency Trade-off

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Abstract:
Mobile ad-hoc network (MANET) is a collection of wireless mobile host forming a temporary network without the aid of any stand-alone in-frastructure or centralized administration. Energy-spectrum aware scheduling (ESAS) scheme is developed to investigate the properties of Energy-efficiency (EE) and spectrum-efficiency (SE) for video streaming over mobile ad hoc networks. Density based node mobility is used to describe the practical mobile scenario where the operation of MANET is very depend on the availability of neighbor nodes. The contribu-tions of this work are twofold: 1) We propose an ESAS scheme with a dynamic transmission range, which significantly outperforms the pre-vious minimum-distortion video scheduling in terms of joint EE and SE performance;2) We derive an achievable EE-SE tradeoff range and a tight upper/lower bound with respect to energy-spectrum efficiency index for various node velocities. An energy and spectrum efficient mobile video transmission can be built on the fundamental design guidelines by using our proposed method.

Keywords: Energy-efficiency, spectrum-efficiency, mobile ad hoc networks, multimedia communications

I. INTRODUCTION

A network is an assemblage of people or systems or organi-zations who considered together as being related in some way who tend to contribute their information collectively for their business purpose which can be done as wired or wire-less. Ad-hoc networks are wireless networks where nodes can share their information with each other. Ad-hoc net-works form spontaneously without a need of an underlying structure or centered controller. A routing protocol is a protocol that specifies how routers communicate with each other, disseminating information that enables them to select routes between any two nodes on a computer network. Each router has a priori knowledge only of networks attached to it directly. A routing protocol shares this information first among immediate neighbors, and then throughout the net-work. This way, routers gain knowledge of the topology of the network. An ad hoc routing protocol is a convention, or standard, that controls how nodes decide which way to route packets between computing devices in a network [1]. A Mobile Ad-hoc network (MANET) is a multi-hop wireless network designed by a group of mobile node that have Wire-less features. MANET is an assemblage of wireless nodes that dynamically create a wireless network among them without any infrastructure. Ad-hoc is an imparted mode that allows computers to directly interchanged information with each other without a router. In Latin, ad-hoc means “for this” meaning “for this special purpose”. In ad hoc networks, nodes do not start out familiar with the topology of their networks; in-stead, they have to discover it [2]. Mobile ad-hoc network also called a Mobile Mesh Network. It is a self-configuring N/W of mobile devices connected by wireless links.

Typically, each node in MANETs is powered by a battery, and thus energy-efficiency (EE) is a significant performance metric for the networks. Moreover, due to the scarcity of spectrum, spectrum-efficiency (SE) is also a critical design consideration for MANETs, in particular for high rate multimedia communications. Unfortunately, EE and SE do not always come together and sometimes even conflict with each other [3]–[4], and thus how to balance EE and SE is a worthy research topic. Actually, there have been many works studying EE, SE, or the combination of the two in the framework of wireless communications.

Fig.1. Layout of a MANET Network

However, very few works focused on how the node mobility impacts EE and SE on the video streaming over wireless networks. . All the nodes follow a random walk mobility model, i.e., each node can randomly and independently decide the mobility direction and velocity at each time slot. When the node velocity is high, EE is high and SE is low. In contrary, when the node velocity is low, EE is low and SE is high. This is an interesting phenomenon which motivates us to study the properties of EE and SE for video streaming over MANETs.The objective of this work is to further investigate and understand the relationship between the EE and SE for video streaming over MANETs. We aim at providing a theoretical analysis of fundamental EE-SE tradeoff through developing an energy-spectrum-aware scheduling scheme in the context of mobile video transmission. The previous works on EE mainly focused on transmission schemes to minimize total energy consumption. . To be more specific, the bits-per-Joule capacity to character-ize the efficiency of general data transmission was proposed in [5]–[6], and the optimal scheduling for minimizing transmission energy was considered in [3], [8], [9] by dynamically changing the packet transmission time. In terms of SE, [10] presented some crucial design rules for band-width efficient networks, and [11], [12]–[13] proposed numerous scheduling schemes where multiple possible relays are utilized when the direct transmission is unavailable. Moreover, there are also some works analyzing the EE-SE tradeoff. More precisely, [4] studied the EE-SE tradeoff in an OFDM system, and an analytical scheduling scheme was developed in [15] to investigate the tradeoff between total energy consumption and end-to-end transmission rate. However, these methods are distinctly different from our work. They only considered a static wireless network with a single source-destination pair, while our work studies multi-user wireless video transmission with density based mobility velocity, to overcome the complexity of the random walk mobility.

II. RELATED WORK

We consider an ad hoc wireless network with 15 nodes randomly placed within a 100m-by-100m square. In such a network, the signal-to-interference-plus-noise-ratio (SINRij) and the link capacity (Cij) from node i to node j can be calculated :

$$SINR_{ij} = \frac{d_{ij}^{-\alpha}}{BN + \sum_{\substack{k \neq j \\ k \neq i}} d_{kj}^{-\alpha}} \qquad (1)$$

$$C_{ij} = \frac{B}{2}\log(1 + \gamma SINR_{ij}) \qquad (2)$$

- Where dij is the distance between node i and node j, α denotes the path loss exponent, N represents the power spectral density of the noise, B is the bandwidth and ϒ is the coding gain. In this model the transmission power is equal at all nodes. In the following, we will assume the nodes are static and base our analysis on the capacity map derived from 2, with N = 0, α= 2 and ϒ = 1. While this is a simplified model for the wireless ad hoc network, the analysis we present would be easily extended to more sophisticated link capacity calculation.

III. VIDEO QUALITY

Suppose that there are Z (Z ∈ N) video flows in MANETs. For each flow z (z ∈ [1, Z]), it is classified into one of Kclasses (i.e., C1, . . . , CK). A class Ck (1 ≤ k ≤ K) can be described by a triplet (Dk,Wk, λk), where Dk represents the delay deadline of Ck, Wk denotes the average source rate of each flow in Ck, and λk stands for the quality impact factor of Ck [24]. In addition, for Ck, the maximum transmission rate streaming over link l is denoted by Tl,k, depending on the transmission power Et [4]2. According to the polling-based time allocation [1], the effective transmission rate for flow z over link l can be computed by Tl,k × tl,z, where tl,z reflects the time allocation proportion for video flow z streaming over link l [25]. xz = {tl,z} stands for the scheduling of video flow z and X = [x1, x2, . . . , xZ] denotes the joint scheduling for all Z video flows. Dz(X) represents the end-to-end delay for delivering flow z employing X. Based on the previous analysis, Dz(X) can be calculated by:

$$D_z(\mathcal{X}) = \sum_{l, t_{l,z} > 0} \frac{L_k}{T_{l,k}\, t_{l,z}}, \quad z \in C_k, \qquad (1)$$

Where Lk represents the average packet length of Ck [24].Therefore, the received video quality from source n (n ∈ N),Qn, is given by:

$$Q_n(\mathcal{X}) = \sum_{k=1}^{K} \sum_{z=1}^{N_{n,k}} \lambda_k W_k I(D_z(\mathcal{X}) \leq D_k), \qquad (2)$$

Where Nn,k shows the number of flows in class Ck from n,and I(·) represents an indicator function. Also, the average video quality is defined as:

$$\bar{Q} \triangleq \sum_{n=1}^{N} \frac{Q_n}{N}. \qquad (3)$$

Hence, we should design an appropriate scheduling schemeX to maximize the average video quality Q¯, such that

$$\arg\max_{\mathcal{X}} \left\{ \bar{Q}(\mathcal{X}) \right\}, \qquad (4)$$

$$s.t. \sum_{z=1}^{Z} t_{l,z} \leq 1, \forall l, \qquad (5)$$

$$D_z(\mathcal{X}) \leq D_k, \ \forall z \in C_k, \ z = 1, \ldots, Z, \ k = 1, \ldots, K. \ (6)$$

Specifically, (5) shows the time allocation for each link, and (6) reflects the delay-sensitive scheduling requirement for each video flow.

III.I ENERGY-EFFICIENCY AND SPECTRUM-EFFICIENCY

We use an additive independent model to characterize the average one-hop energy consumption ¯E, i.e.,

$$\bar{E} = E_t + E_m, \qquad (7)$$

Where Et stands for the energy consumption introduced by packet transmission, and Em denotes the energy consumption caused by node mobility. According to the free space propagation model [23], Et can be approximated by:

$$E_t \approx \frac{1}{G_t G_r} \left(4\pi \bar{R}\right)^2 E_r = C_1 \bar{R}^2, \qquad (8)$$

Where Er reflects the received energy,

$$\bar{R} \triangleq \sum_{n=1}^{N} R_n / N$$

N, and Gt (Gr) represents the transmitting (receiving) antenna gain. For simplicity, we set

C1= $\frac{E_r}{G_t G_r}(4\pi)^2 = 1$ without loss of generality. Likewise, Em can be modeled by a linear model related to the average node mobility velocity

$\bar{V} \triangleq \sum_{n=1}^{N} V_n/N,$ ie..

$$E_m \approx C_2 \cdot \bar{V}, \quad (9)$$

Where C2 is a positive constant which can also be set as one for computation convenience [25]. In addition, we denote by $\bar{H}$ the average number of hops for each video flow, and thus we get

$$\bar{E} = \bar{H} \cdot (E_t + E_m) \propto \bar{H} \cdot (\bar{R}^2 + \bar{V}). \quad (10)$$

Similar to [5], [6], we can characterize the average spectrum utilization $\bar{B}$ as:

$$\bar{B} = \sum_{l=1}^{\bar{H}} \sum_{z=1}^{Z} \frac{t_{l,z}}{\bar{H}Z}. \quad (11)$$

Therefore, based on the above discussions, we formally define the energy-efficiency ψ and spectrum-efficiency φ as:

$$\psi \triangleq \frac{\bar{Q}}{\bar{E}} \text{ and } \phi \triangleq \frac{\bar{Q}}{\bar{B}}. \quad (12)$$

IV. ENERGY-SPECTRUM-AWARE SCHEDULING

In this section, we design an ESAS scheme based on DMDS, by modifying the transmission range for various node mobility velocities. We state the property of the scheme as follows.

Theorem 1: Let N be the number of nodes in a MANET. To obtain the optimal solution of (4), the average transmission range $\bar{R}$ in ESAS is a function of the average node mobility velocity $\bar{V}$.

IV.I MOBILITY PROPERTY

Lemma 1: The expectation of Ln satisfies

$$\mathbb{E}(L_n(\theta_n)) \propto \frac{(V_n + R_n)\, e^{-\theta_n(V_n+R_n)}}{V_n e^{-\theta_n V_n}}. \quad (13)$$

Lemma 2: We have the asymptotic formula as:

$$\mathbb{P}(L_n > x) = \frac{(V_n - \theta_n(V_n+R_n))e^{\theta_n(V_n+R_n)-V_n}}{(1-\theta_n(V_n+R_n))\theta_n(V_n+R_n)} e^{-\theta_n(V_n+R_n)x}(1+o(1)). \quad (15)$$

IV.II AVERAGE NUMBER OF HOPS

Now, we analyze the average number of hops $\bar{H}$ for any video stream. Based on Lemma 2, we propose Lemma 3 to connect $\bar{H}$ with N, $\bar{V}$, and $\bar{R}$.

Lemma 3: For each stream, the expectation of the number of hops from the source to destination is

$$\mathbb{E}(H(\bar{V})) \sim \left(1 + O\left(e^{-\varepsilon\bar{V}}\right)\right) \frac{e^{\sqrt{\log N}}}{\sqrt{\log N}} \frac{(1-\bar{R})}{(\bar{V}+\bar{R})\, e^{\bar{V}+\bar{R}}} e^{\bar{V}}. \quad (16)$$

Lemma 4: When N →∞, we have

$$\mathbb{P}\left(\bar{H} > \frac{e^{\sqrt{\log N}}}{\sqrt{\log N}}\right) \approx \frac{\bar{R}e^{-\bar{R}}}{(\bar{R}+\bar{V})\log \bar{R}} \Gamma\left(\frac{\bar{R}}{\bar{R}+\bar{V}}\right) \beta^{-\frac{\bar{R}}{\bar{R}+\bar{V}}} N^{-\frac{\bar{R}}{\bar{R}+\bar{V}}} (1+o(1)), \quad (21)$$

where Γ is the *Euler Gamma function*, and $\beta = \frac{\bar{V}e^{\bar{R}+\bar{V}}}{1+\bar{R}+\bar{V}}$.

IV.III AVERAGE VIDEO QUALITY

Generally, the average video quality $\bar{Q}$ at the destination is dependent on the average traveled distance for any stream from source to destination [3], since this distance for any node, denoted by Ce, contains the information of $\bar{V}$, $\bar{R}$, and E(Ln). In the framework of ESAS, Ce has the following property.

Lemma 5: The average value of Ce satisfies

$$\mathbb{E}(C_e) \propto \bar{V} \times \mathbb{E}(L_n) \times \frac{e^{\sqrt{\log N}}}{\sqrt{\log N}} \frac{(1-\bar{R})}{\bar{R} \cdot e^{\bar{V}+\bar{R}}} e^{\bar{V}}. \quad (22)$$

V. ENERGY-SPECTRUM EFFICIENCY TRADEOFF

Theorem 2: Let N be the number of nodes in a MANET.Using ESAS with RWMM, a wide range of energy-spectrum efficiency tradeoff is possible for any $0 \le \bar{V} < \Theta(1)$, and the minimal values of ψ and φ satisfy ψ =√N φ . Moreover, for any $\bar{V}$, the maximum value of ESEI, logN (ψ/φ), is 1.5 and the minimum value is −0.5,First, Lemma 6 and Lemma 7 analyze lower bounds on the expectation value of ψ and φ for each velocity, which indicates that each bound of ψ and φ locates on one curve .Then, Lemma 8 shows that, for $0 \le \bar{V} < \Theta(1)$, there exists a broad ψ − φ tradeoff range which is a linear function (Corollary 4). Lemma 6: Let N be the number of nodes in a MANET, and $\bar{Q}$ be the average video quality which is defined. For any given average node mobility velocity $\bar{V}$, using ESAS, the expectation value of energy-efficiency ψ is related to $\bar{V}$ and $\bar{Q}$, and there exists a constant Cψ (Cψ ∈ R+)satisfying

$$\mathbb{E}(\psi(\bar{V}, \bar{Q})) \ge C_\psi, \quad \forall \bar{V} \in \mathbb{R}_+. \quad (25)$$

We start by defining the potential function $\mathcal{Q} = \frac{1}{N}\sum_{n=1}^{N}(Q_n - \bar{Q})$ and will use the following propositions to prove Lemma 6.

Proposition 1:

$$\forall \bar{V} \in \mathbb{R}_+, \sum_{n=1}^{N} (\mathbb{E}(Q_n(\bar{V})) | \mathcal{Q})^2 = N\bar{Q}^2 + \sum_{n=1}^{N} \mathcal{Q}^2$$

Proposition 2: ∀ $\bar{V}$ ∈ R+, there exists a constant CQ (CQ ∈ R+), such that

$$\mathbb{E}\left(\sum_{n=1}^{N} Q_n(V_n)/N | Q_n(V_n)\right) \ge C_Q. \quad (26)$$

Lemma 7: Let N be the number of nodes in a MANET, and $\bar{Q}$ be the average video quality. For any given average node mobility velocity $\bar{V}$, using ESAS, the expectation value of spectrum-efficiency φ is related to $\bar{V}$ and $\bar{Q}$, and there exists a constant Cφ (Cφ ∈R+) satisfying:

$$\mathbb{E}\left(\phi\left(\bar{V},\bar{Q}\right)\right) \geq C_{\phi}, \quad \forall \bar{V} \in \mathbb{R}_{+}. \qquad (27)$$

Lemma 8: Let N be the number of nodes in a MANET. Using ESAS,for a given average node mobility velocity $\bar{V}$, we can show that the minimum energy-efficiency ψ and the minimum spectrum-efficiency φ can be achieved simultaneously when each node cannot deliver the packet to its best relay.

VI. EXPERIMENTAL RESULT

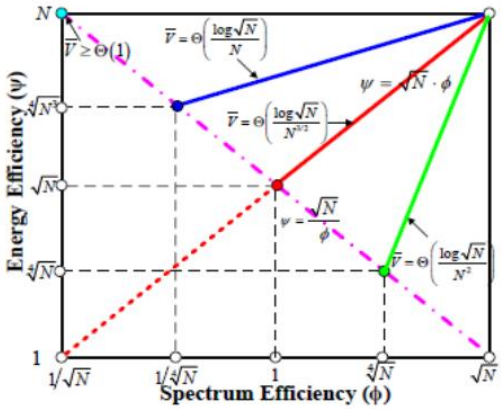


Fig.2 Energy-spectrum efficiency tradeoff range for different velocities

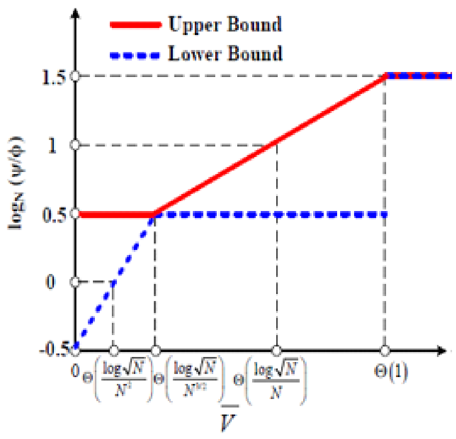
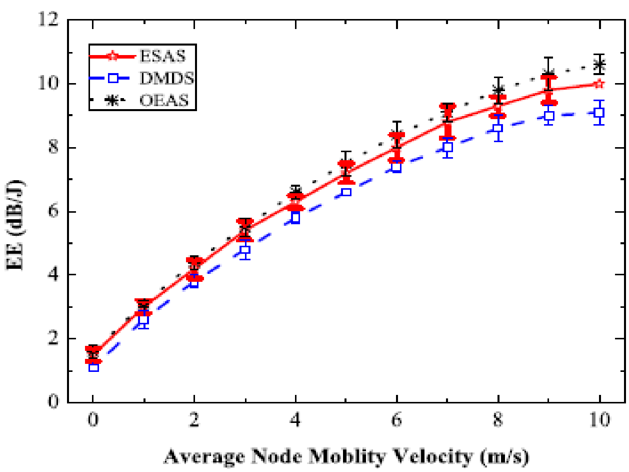
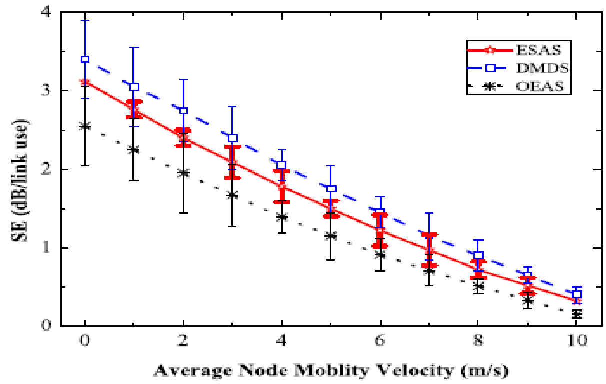


Fig.3 Energy-spectrum efficiency Index logN(ψ/φ) as a function of velocity $\bar{V}$.



(a) EE



(b) SE

Fig.4 EE and SE performance for video streaming over MANETs with various node mobility velocities.

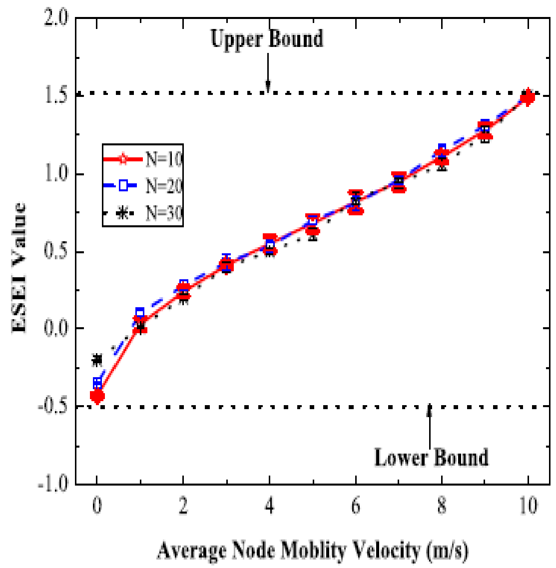


Fig.5 The value of ESEI under various $\bar{V}$ and N

VII. 6 CONCLUSION

We have studied the performance of video streaming over mobile ad hoc networks from the perspectives of energy efficiency and spectrum-efficiency. In general, our contributions are twofold. First, we proposed an energy-spectrum aware scheduling scheme with dynamic transmission range. In particular, when the node mobility is high enough, it is possible to achieve almost a constant energy-efficiency and spectrum-efficiency as the number of nodes increases. Second, we derived an achievable energy-efficiency and spectrum efficiency tradeoff range and upper/lower bounds with respect to the energy-spectrum efficiency index for various node velocities.

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