Incorporating User Willingness for Message Forwarding in Multi-Hop Content Distribution Scenarios

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***Abstract*—A video streaming scenario in a wireless Ad Hoc network is considered. In this scenario, nodes are interested in streaming a video available at a single source node. The video will be disseminated throughout the network in a multi-hop fashion such that some intermediate nodes spend part of their energy for relaying the video. The end-users have different preferences in terms of the amount of energy they prefer to spend for forwarding video. We categorize them into two sets: the high-willingness-to-forward nodes and the low-willingness-to-forward nodes. As incentive, the nodes which contribute more in the network receive high video quality while the rest of the nodes receive a basic video quality. The Scalable video coding (SVC) technique is exploited for streaming different video qualities to the nodes based on their energy contributions. We propose using two broadcast trees to connect the nodes based on their contribution level. Constructing the broadcast tree is based on a decentralized game-based algorithm. Simulation results show that by having more nodes with high contribution in the network, the users' quality of experience as well as the network efficiency in terms of bits per joule increases.**

I. Introduction

Demands for video streaming services have significantly increased among the Internet users over the past years [1]. It is estimated that by the end of 2019, three-fourths of the total worldwide mobile traffic will be occupied by video streaming services [2]. Furthermore, multi-hop communication becomes important for future wireless mobile networks. Therefore, it is essential for the future multi-hop networks to support video streaming services. This paper focuses on video streaming in a multi-hop broadcast scenarios. In these scenarios, nodes are physically close to each other in the sense that there exists at least one multi-hop reliable radio link between any two nodes. Moreover, there is a single source node streaming a video to all other nodes in the network in multi-hop fashion.

Apart from explicitly assuming video streaming services, [3–5] consider disseminating a common message which may contain any type of data or services in multi-hop broadcast networks. Aiming at minimizing the total network energy, central algorithms for optimizing the transmit power at the nodes are proposed in [3], [4]. Furthermore, a game-based distributed algorithm which exploits the broadcast nature of the wireless channel is proposed in [5]. The authors of [6] optimize the transmissions in the multi-hop broadcast network for minimizing the network latency.

Concerning video streaming services in wireless networks, the authors of [7] and [8] optimize the network for video steaming services. In [7], the authors study employing scalable video coding (SVC) [9] transmission over WiMax networks. They propose a sub-optimal algorithm which improves the video quality received by the users with higher WiMax radio resource utilization. Moreover, the authors of [8] investigate the SVC distribution over wireless mesh networks. They consider the IEEE 802.11g radio access technology and use a centralized algorithm aiming at maximizing the minimum video quality perceived by the users in terms of peak signal to noise ratio under the constraint of limited resource available for allocation. In [10], a cross-layer framework which utilizes the underlay resources efficiently for accommodating SVC video streams in multi-hop networks is proposed.

Considering that nodes are smart phones and tablets that are owned by the end-users, incorporating user preferences in terms of their willingness to spend part of their battery's energy for forwarding the data to others plays a key role for the success of the multi-hop networks in real-life implementations. Moreover, the amount of energy that a user is willing to use in forwarding highly influences the coverage area of the whole network and the overall performance. Therefore, smart algorithms which take user preferences into account are of interest [11], [12]. In [11], the authors studied the important parameters in terms of energy consumption and relaying duration that may affect the users' willingness for acting as a relay in Ad Hoc networks. The authors of [12] proposed using SVC for video transmission with different received qualities at the nodes. They do not address the Ad Hoc networks in which the user should collaborate and forward video to other nodes.

In this paper, a video streaming multi-hop broadcast scenario is considered. Based on the user preferences, nodes are modeled in two different categories: firstly, low-willingness-to-forward nodes (LWF) which want to invest a low amount of energy in forwarding; secondly, high-willingness-to-forward nodes (HWF) which want to invest a high amount of energy in forwarding. A distributed game-based algorithm which determines how the video will be disseminated throughout

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the network is proposed. To motivate the nodes to invest more energy in forwarding, a high video quality (HQ) will be received by the HWF nodes as a reward, whereas LWF nodes receive only basic video quality (BQ). To distribute different video qualities throughout the network, we employ the SVC technique in which nodes need more enhancement layers to receive a HQ video.

The rest of this paper is organized as follows. In Section II the network model is described and the problem is stated. Section III explains the limitations of the nodes for topology formation along with some definitions. We propose our algorithm in Section IV followed by simulation results in V. Finally Section VI concludes the paper.

II. Network Model

The network is composed of a source node S and a set of N other nodes denoted by $\mathcal{P} = \{1, 2, \ldots, N\}$ which are interested in receiving a common message from the source. All nodes are wireless and randomly distributed over a specific region. The nodes are controlled by end-users which may have different preferences for forwarding the message. That is, some nodes may spend a higher amount of energy for message forwarding than others.

The message at the source is a video encoded by the SVC scheme [9]. The SVC-based video is scalable in three dimensions which are denoted by spatial, temporal and quality (s, t, q) dimensions. Each dimension has several layers and each layer has a specific bit rate requirement. The video must be decoded in a successive manner such that in order to decode the layer $l + 1$, having layer 1 to layer l at the decoder is necessary. Having more layers in each of the dimensions results in a higher video quality [13]. In this network, based on their contribution in the network, the users receive different numbers of video layers and experience different video qualities. For simplicity, we assume that the nodes in the network are divided into two categories based on their willingness to forward the video to others: the nodes with high-willingness-to-forward and low-willingness-to-forward, denoted by HWF and LWF nodes, respectively. We assume that LWF nodes receive layer 1 to layer l_L of SVC which result in a BQ video while the HWF nodes, in addition to the layers 1 to l_L, receive the layers from $l_L + 1$ to l_H, which result in HQ video, see Fig. 1. We call the layers from $l_L + 1$ to l_H as enhancement layers for HWF nodes.

Two different amounts of energy have to be spent by LWF and HWF nodes regarding to the layers that they transmit. We assume that LWF nodes and HWF nodes spend the maximum amount of $E_L^{\max}$ and $E_H^{\max}$ in this network, respectively, such that $E_L^{\max} < E_H^{\max}$. The playback duration of a video in the network is denoted by T_v, which is fixed. Therefore, in correspondence to the maximum amount of energy, the maximum transmit power of the LWF and HWF nodes are given by $p_L^{\max}$ and $p_H^{\max}$, respectively.

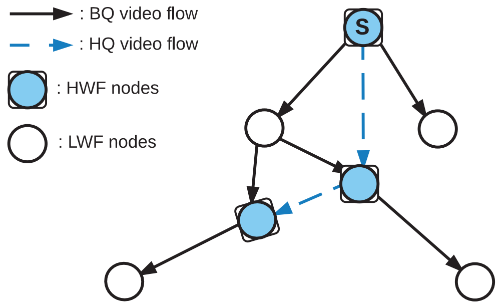

Fig. 1: A network with 4 LWF nodes and 3 HWF nodes. Black arrows show the flow of the BQ video. The dashed arrows represents the HQ video streaming among the HWF nodes.

III. Broadcast Tree

Due to the limited transmit power, the video has to be disseminated in a multi-hop manner such that some nodes must forward the video to others. A node j that forwards the video to others is called a *parent node* for its respective receivers. The nodes which receive the video from a parent node j are called the *child nodes* of the parent node j. Every child node could be a parent node if it forwards the message to other nodes, while the source node is always a parent node. The connection between a parent node and its child nodes in the whole network results in a tree graph, called broadcast tree. The broadcast tree determines the flow of video streaming in the network. Due to having two categories of nodes, i.e., LWF and HWF, we propose using two broadcast trees. The broadcast tree bl distributes the layers required to receive BQ video, that is layers 1 to l_L, while the broadcast tree bh is for disseminating the enhancement layers for HWF nodes so that they can receive the HQ video. In the following, we refer to the broadcast trees by b such that $b \in \mathcal{B} = \{bl, bh\}$.

Recall that, in order to decode a specific layer in SVC, receiving the layers below is necessary. Hence, a node j of type LWF just belongs to broadcast tree bl while a node of type HWF must belong to both broadcast trees bl and bh. The maximum transmit power that node i can spend for broadcast tree $b \in \mathcal{B}$ is denoted by $p_i^{\max,b}$. For constructing of broadcast tree bl the maximum transmit power of LWF and HWF nodes is $p_i^{\max,bl} \leq p_L^{\max}$. For bh broadcast tree construction, a HWF node i can use the maximum transmit power of $p_i^{\max,bh} \leq p_H^{\max} - p_i^{\max,bl}$ that depends on the power it spends in construction of broadcast tree bl.

We assume a threshold model for decoding at child nodes, that is a minimum signal to noise ratio (SNR), denoted by γ^{th}, is required at a child node for successful decoding of the data transmitted from its parent node. Given the channel gain $|h_{i,j}|^2$ between parent node j and child node i, the required transmit power at the parent node j to guarantee the γ^{th} at the child node i in broadcast tree b can be calculated by

$$p_{i,j}^{\text{uni},b} = \frac{\gamma^{\text{th}} \sigma^2}{|h_{i,j}|^2} \qquad (1)$$

in which σ^2 is the noise power and $p_{i,j}^{\text{uni},b} < p_j^{\max,b}, b \in \mathcal{B}$.

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Note that we assume there is no interference and collision in the network.

In a broadcast tree, a child node has one parent node, while a parent node may have more than one child node. In this case the parent node transmits the video via multicast transmission to all its child nodes at once. The parent node j in a unicast transmission to child node i must spend the energy of

$$e_{i,j}^{\mathrm{uni},b} = p_{i,j}^{\mathrm{uni},b} \times T_v \tag{2}$$

in which $b \in \mathcal{B}$. In (2), node i can receive the video from node j if $e_{i,j}^{\mathrm{uni},b} < E_j^{\max}$. In a multicast transmission, the energy consumption of parent node j for multicasting a video with bit rate R_l in broadcast tree b to set $\mathcal{M}_j^b$ of its child nodes is calculated by

$$E_j^{\mathrm{Tx},b}(\mathcal{M}_j^b) = \max_{i \in \mathcal{M}_j^b} \left\{ e_{i,j}^{\mathrm{uni},b} \right\}. \tag{3}$$

The total energy that a node j spends in this network must be less that the its energy consumption constraint $E_j^{\max}$, that is

$$E_j^{\mathrm{Tx}} = \sum_{b \in \mathcal{B}} E_j^{\mathrm{Tx},b} \leq E_j^{\max}. \tag{4}$$

If node j is of type LWF, then $j \notin bh$ and hence $E_j^{\mathrm{Tx},bh} = 0$. That is, for node j of type LWF $E_j^{\mathrm{Tx}} = E_j^{\mathrm{Tx},bl} \leq E_L^{\max}$. The energy consumption at HWF nodes is $E_j^{\mathrm{Tx}} = E_j^{\mathrm{Tx},bl} + E_j^{\mathrm{Tx},bh} \leq E_H^{\max}$.

Note that for broadcast tree formation, the broadcast tree bl for transmission of BQ video will be formed first. Then, the HWF nodes with remaining energies out of the formation of bl, construct the bh broadcast tree for streaming of enhancement layers. There are different approaches in constructing a broadcast tree [5] [14]. To form the broadcast trees in a decentralized way, we propose a game-theoretic framework.

IV. Video Dissemination

In this section, we discuss how the nodes form a broadcast tree in a decentralized way using a game-theoretic approach. The proposed game is child-driven, that is, a child chooses a parent node in order to receive the video from it. We first define the two terms of distance rank and neighboring nodes before explaining the game.

A. Distance rank and neighboring nodes

One of the most important issues in broadcast tree formation by a decentralized approach is to prevent loop occurrence in tree structure [15]. Since in a decentralized algorithm, the nodes decide based on their local information, a loop may occur between some nodes if they connect to a wrong parent node. In this case, the nodes in the loop and their child nodes loose their connection to the source and miss the content. In order to prevent loop occurrence, we define a distance rank D_i for every node $i \in \mathcal{P}$. Distance rank D_i shows the distance of a node from the source. A child node can connect to a parent node if the distance rank of the parent node is lower than that of the child node, that is, the parent node must be closer to the source.

The neighborhood of a node, is defined as the region which can be covered by a node for video transmission based on its transmit power constraint. The set of neighboring nodes of node i are the nodes which can be served by node i, considering the transmit power constraint at node i and defined as

$$\mathcal{N}_i = \left\{ j \,\middle|\, j \in \mathcal{P} \cup \{S\}, p_{i,j}^{\mathrm{uni},b} < p_i^{\max,b} \right\}. \tag{5}$$

A child node i can connect to a parent node j if they are in each others' neighborhood and if the distance rank of the parent node is less than that of child node.

B. Game properties

Every node in the network receives the layers of SVC which are required for BQ video. The base layer which is carried by broadcast tree bl with bit rate R_L is required at LWF nodes to make BQ video quality and at HWF to help decoding the higher layers. Therefore, the players of the game for receiving the BQ video quality are all the nodes of the network except for the source, i. e., $\mathcal{P}$. The HWF nodes which are the players of the game for receiving the HQ video quality are denoted by $\mathcal{H}$.

In the following, we explain the game for broadcast tree bl. Using the same principle, the bh broadcast tree is constructed. In broadcast tree bl in which all the nodes of $\mathcal{P}$ are involved for broadcast tree formation, the action of player i in $\mathcal{P}$ is to choose one of its neighboring nodes $j \in \mathcal{N}_i$ as its parent node in a way to minimize its cost. The action of node i and its action set are denoted by a_i and $\mathcal{A}_i$, respectively, such that $a_i \in \mathcal{A}_i$. The action space of a node can formally be defined as

$$\mathcal{A}_i = \left\{ j \,\middle|\, j \in \mathcal{N}_i, D_j < D_i, i \in bl, j \in bl \right\} \tag{6}$$

which says that the neighboring nodes of node i which have lower rank distance to the source node than node i can be chosen by it as parent node. The actions of other nodes except the node i is denoted by a_{-i} and action profile of a game is denoted by $\mathbf{a} = (a_1, \ldots, a_N) \in \mathcal{A}$. The action set of the game is defined as $\mathcal{A} = \mathcal{A}_1 \times \mathcal{A}_2 \times \ldots \mathcal{A}_N$, such that for every action profile we have $\mathbf{a} \in \mathcal{A}$. Based on the action profile of the game, a non-negative cost C_i^{bl} is assigned to each of the players $i \in \mathcal{P}$. More precisely, the cost of node i if it chooses node j as its parent is defined as $C_i^{bl}(j, \mathbf{a}_{-i}) : \mathcal{A} \to \mathbb{R}$. With the above definitions, the non-cooperative game can be defined as $G = (\mathcal{P}, \{\mathcal{A}_i\}_{i \in \mathcal{P}}, \{C_i^{bl}\}_{i \in \mathcal{P}})$.

We use the cost sharing game model in defining the costs of the nodes in the network. Cost sharing games can be applied in communication networks where the nodes may transmit the data by multicast [5]. In our model, when two or more child nodes join together and form a multicast receiving group to get data form parent node j, the cost of the transmission from the parent node j is shared among the child nodes in $\mathcal{M}_j^{bl}$. We consider the Marginal Contribution (MC) principle [16] to define the cost at the nodes. By the MC rule, in broadcast to the child node in $\mathcal{M}_j^{bl}$, the cost of the video streaming is assigned to the node $i \in \mathcal{M}_j^{bl}$ whose link requires the highest unicast energy which is determined by (3). In other words, if the link between node i and its parent node j needs the highest energy consumption among all the child nodes of $\mathcal{M}_j^{bl}$, then the cost allocated to node i is the difference between the energy spent by parent node j for video streaming defined in (2) and the second highest required energy consumption. More precisely, the cost of child node i in broadcast tree bl by choosing the the parent node j is defined as

$$C_i^{bl}(j, \mathbf{a}_{-i}) = E_j^{\mathrm{Tx},bl}(\mathcal{M}_j^b l) - E_j^{\mathrm{Tx},bl}(\mathcal{M}_j^{bl} \backslash \{i\}) \qquad (7)$$

in which $\mathcal{M}_j^{bl} \backslash \{i\}$ is the set of the child nodes of j except the node i in broadcast tree bl. Based on Eq. (7), if the joining or leaving node k to the child nodes of $\mathcal{M}_j^{bl}$ does not change the energy consumption at node j, the cost of node k is zero since it does not impose additional energy consumption at node j.

Since the costs at the nodes are defined based on the energy consumption of their parent nodes, reducing the cost at every individual node reduces the total energy consumption in the network. The game G is iterative such that every node updates its action one by one until reaching to an equilibrium point. We use the Nash equilibrium solution concept for this game [16]. A Nash equilibrium in a game is a point at which no player, here the nodes, has the incentive to change its decision since there is no action with lower cost. It is shown in [5] that the cost sharing game with MC cost sharing rule converges to an equilibrium point after some iterations.

When the game for the bl broadcast tree formation ends, the HWF nodes start forming the bh broadcast tree for HQ video streaming. Note that, the forms of the broadcast trees and the role of a HWF node in each of the broadcast trees bl or bh might be completely different. A HWF node may be parent node in broadcast tree bl while it may be a leaf node in broadcast tree bh and vice versa. How the HWF nodes construct bh tree depends on the number of HWF nodes, their situation, the remaining energy for allocating to HQ video streaming and so on.

V. Simulation

A. Simulation Setup

For simulation, a square region with the size of 400 m × 400 m is assumed in which 50 nodes are randomly distributed. The channel model considers path-loss with path-loss coefficient α such that for the nodes i and j with distance $d_{i,j}$ the channel gain is $|h_{i,j}|^2 = (1/d_{i,j})^\alpha$. The path-loss coefficient is set to $\alpha = 3$. We assume that the channel model is constant for the whole video transmission period. The maximum transmit power of LWF nodes is set to $p_L^{\max} = -30$ dBm. This amount of power is equal to the power that HWF nodes spend in the broadcast tree bl together with LWF nodes to get the base layer while the HWF nodes use the rest of their maximum transmit power for streaming the HQ video in the broadcast tree bh. For HWF nodes, the maximum transmit power is set to $p_H^{\max} = -20$ dBm. The noise power and the γ^{th} are assumed to be -100 dBm and 10 dB, respectively. It is also assumed that the modulation and coding scheme utilized at nodes transmits 4 bits per symbol such that the transmit power can be calculated using (1).

TABLE I: Video properties for streaming in the network

Quality levels (QL)	**Layers (s, t, q)**	**Bit rate (Mbps)**	**VQM**
QL1	(0,0,0)	0.72	0.28
QL2	(2,2,0)	6.21	0.61
QL3	(3,4,0)	14.80	1

TABLE II: Different cases for assigning the video qualities

Case A	**Case B**	**Case C**
QL1 → BQ QL2 → HQ	QL1 → BQ QL2&3 → HQ	QL1&2 → BQ QL3 → HQ

We consider SVC encoded CrowdRun sequence from Xiph.org[1] test video database using the information provided in [17]. Based on the analysis in [18], we consider the properties summarized in Table I as the properties of the streamed video. Note that video quality metric (VQM) [19] in Table I for which we have 0<VQM<1, represents the Quality of Experience (QoE) of a user by receiving a set of SVC layers along with all layers below. In Table I, having QL3 at a node means that the user receives 3 layers in spatial domain and 4 layers in temporal domain which indicates that the nodes also receives all layers below associated to the quality levels 1 and 2. Each layer has its own bit stream requirement and results in a different QoE at nodes. By considering the communication bandwidth equal to 20 MHz, the required bit rates in Table I could be transmitted under the considered power constraint at nodes.

For evaluation of the system performance, we assign the video qualities to different broadcast trees based on the three cases shown in Table II. For instance, based on Table I, case A in table II means that the base layer of SVC, which requires a bit rate of 0.71 Mbps per link and results in VQM of 0.28 at nodes, is streamed in the broadcast tree bl. Besides, the layers (2,2,0) associated with QL2 which needs the bit rate of 6.21 Mbps is disseminated for HWF nodes in broadcast tree bh as enhancement layer. In other words, QL1 and QL2 are defined as BQ abd HQ videos, respectively. In the following results, we first initialize the broadcast tree by using Dijkstra algorithm [14] and then apply the game theoretic algorithm explained in IV.

B. Simulation Results

In Fig. 2 the total energy consumed in the network for distributing the BQ and the HQ videos are shown as a function of the percentage of HWF nodes in the network. The BQ and HQ videos used in the network are based on Table II. As it can be seen, when there are HWF nodes in the network, the energy consumption in the network increases as a higher data rate must be delivered to the receiving nodes. By increasing the number of HWF nodes, since the distance between the

[1] https://media.xiph.org/video/derf/

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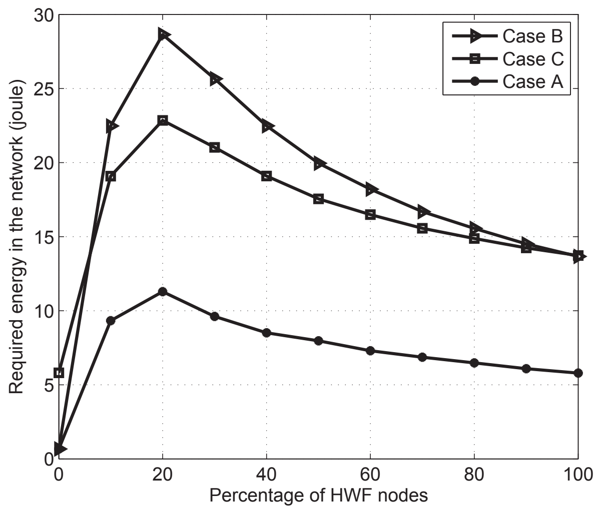

Fig. 2: Total energy consumed in the network for three cases of streaming BQ and HQ video in the network based on Table II.

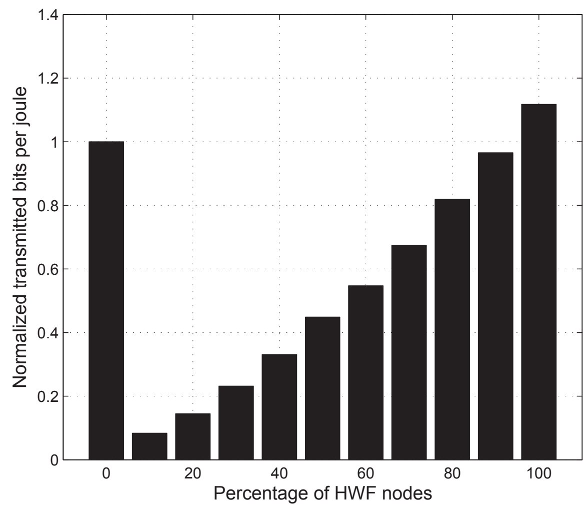

Fig. 3: Efficiency of the algorithm in terms of bits delivered to the nodes per each joule of consumed energy. The result is for case B of Table II and normalized to the case that only the BQ video is distributed.

nodes reduces and more neighboring nodes would be available for each node, a more efficient broadcast tree can be built among the HWF nodes. When all the nodes are HWF, all the nodes participate in forwarding both BQ and HQ videos to each other. As it can be seen in Fig 2, case A has the lowest required energy consumption in the network. The reason is that, in this case the transmitted bit rates for the enhancement layers to stream HQ video is lower than the other two cases. In case A, a maximum QL2 will be received by the nodes while in other cases up to QL3 will be provided for them.

Comparing cases the B and C, although the video qualities received by HWF nodes are the same in both cases, we observe that case C requires lower energy consumption than case C. The reason lies on how the nodes spend their energy for broadcast tree bl. Since in case C more layers and bit rate are allocated for BQ video, the energy spent by the nodes to the broadcast tree bl in case C is more than that of case B. Therefore, unlike case B, in case C the HWF nodes may not have enough energy to participate in forwarding the SVC layers of QL3 in broadcast tree bh. Hence, the total energy consumption in case C becomes less than that of case B. By increasing the number of HWF nodes in the network, the total consumed energies in case B and case C become close to each other since almost the same amount of data is transmitted in both cases.

Fig. 3 shows how many bits are transmitted per joule in the network. The result is for case C and is normalized to the case that there is no HWF node in the network. It can be observed that when there are a few HWF nodes in the network, since the network is sparse regarding to the number of HWF nodes and the distance between the nodes becomes relatively long, high amount of power must be consumed at a HWF node to stream HQ video to others. Therefore, the energy consumption in the network significantly increases, as shown in Fig. 2, and the efficiency of the network in terms of transmitted bits per joule

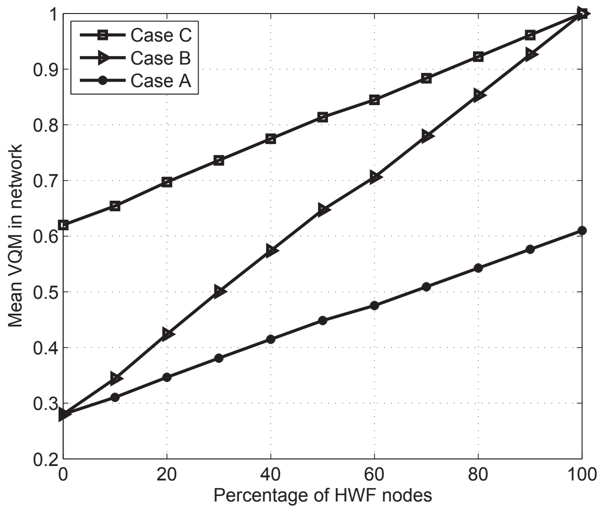

Fig. 4: Average VQM in netwrok as a function of the percentage of HWF nodes in network.

decreases. By increasing the number of HWF nodes, not only the number of nodes which receive high bit rate increases, but also less energy is required for HQ video distribution. Therefore, the efficiency in the network increases. When all the nodes in the network are HWF, the efficiency is higher than the case of having no HWF node in the network.

Fig. 4 shows the quality of the perceived video in terms of average VQM in the network. The result is based on the VQM values in Table I for three cases shown in table II. As it can be expected, by having more HWF nodes and distributing HQ video the average video quality at nodes increases. In cases A and C, when all the nodes of the network are LWF, the nodes experience the lowest quality of the video. By increasing the number of HWF nodes, the average quality of video received at nodes increases. In case A, since the HQ video is associated to QL2 in Table I, the nodes can receive the maximum VQM of 0.61. It is possible to experience the highest possible VQM in case B, but considering Fig. 2, achieving the highest possible quality at all nodes is at the expense of consuming higher energy. Now, we compare Fig. 2 and Fig. 4 for the cases A and B when all nodes are HWF. It can be observed that in Fig. 2, the energy consumption in the whole network in case B is more than two times of that of case A, while the increase in average VQM in case B compared to case A in Fig. 4 is less than two times. In other words, although in case B more energy is consumed in the network than case A, the rate of the increase in VQM is less than the increase in energy consumption.

By considering case C in Fig. 4 it can be seen that when the number of HWF nodes are low, the average VQM of the users in this case is more than that of the other two cases. For instance, when 50 percent of the nodes are HWF nodes, the average VQM of the nodes in case C is 40 percent more than that of case B, while, as it is shown in Fig. 2, the energy consumption in the network in case C is even about 15 percent lower. It means that, the average VQM and energy consumption in the network highly depends on how the SVC layers are assigned to the different broadcast trees. It can be interpreted that, when not all nodes of the network are of type HWF, allocating more layers to the common broadcast tree *bl*, i.e., an approach like case C in Table II, may results in a high averaged VQM while the energy is utilized in a reasonable way.

VI. Conclusion

We studied a video streaming scenario in a multi-hop wireless network in which the nodes of the network have different willingness in terms of forwarding video for other nodes. The SVC-based video is assumed for streaming such that the nodes which contribute more in the network receive higher video quality. We showed that having more contributing nodes in the network can result in a higher quality of experience of the users as well as energy efficiency in terms of transmitted bits per joule. Moreover, we observed that consuming higher energy in network does not necessarily lead to a better quality of experience at the users. Apart from energy consumption, how the layers of SVC-based video are distributed among the nodes highly affects the quality of experience at the users.

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