March 2013 IJMIE Volume 3, Issue 3 ISSN: 2249-0558

EFFICIENT PEER-TO-PEER VIDEO STREAMING FOR COOPERATIVE NETWORKS

S.Srithar[*]

Mr.S.AthiNarayanan[**]

Abstract—For real-time video broadcast where multiple users are interested in the same content, mobile-to-mobile cooperation can be utilized to improve delivery efficiency and reduce network utilization. Under such cooperation, however, real-time video transmission requires end-to-end delay bounds. Due to the inherently stochastic nature of wireless fading channels, deterministic delay bounds are prohibitively difficult to guarantee. For a scalable video structure, an alternative is to provide statistical guarantees using the concept of effective capacity/bandwidth by deriving quality of service exponents for each video layer. Using this concept, we formulate the resource allocation problem for general multihop multicast network flows and derive the optimal solution that minimizes the total energy consumption while guaranteeing a statistical end-to-end delay bound on each network path. A method is described to compute the optimal resource allocation at each node in a distributed fashion. Furthermore, we propose Embedded Sleep Scheduling & Prims Algorithm for energy-efficient flow selection from the set of directed acyclic graphs forming the candidate network flows. The flow selection and resource allocation process is adapted for each video frame according to the channel conditions on the network links.Considering different network topologies, results demonstrate that the proposed resource allocation and flow selection algorithms provide notable performance gains with small optimality gaps at a low computational cost.

Keywords—Scalable video coding, real-time video broadcast, statistical QoS guarantees, mobile-to-mobile cooperation,sleep scheduling, prims Algorithm.

* Student M.Tech (IT), PSN College of Engineering and Technology,Tirunelveli

** Associate Professor M.Tech, Associate Professor, M.Tech (IT), PSN College of Engineering and Technology, Tirunelveli

I. INTRODUCTION

The real-time nature of video broadcast demands qualityof- service (QoS) guarantees such as delay bounds for end-user satisfaction. Given the bit rate requirements of such services, delivery efficiency is another key objective.The H.264/AVC video coding standard [1] is designed to provide high coding efficiency that is suitable for wireless video transmission. To provide a network-friendly design, the scalable video coding (SVC) extension of H.264 [2]allows rate scalability at the bitstream level by generating embedded bit streams that are partially decodable at different bitrates with degrading quality. The basic level of quality is supported by the base layer and incremental improvements are provided by the enhancement layers. Video source rate scalability can be achieved with temporal, spatial, or quality scalability [2].Deterministic delay bounds are prohibitively expensive to guarantee over wireless networks. Consequently, to provide a realistic and accurate model for quality of service, statistical guarantees are considered as a design guideline by defining constraints in terms of the delay-bound violation probability. The notion of statistical QoS is tied back to the well-developed theory of effective bandwidth [3]and its dual concept of effective capacity [3]. For scalable video transmission, a set of QoS exponents for each video layer are obtained by applying the effective bandwidth/capacity analyses on the incoming video stream to characterize the delay requirement. The problem of providing statistical delay bounds for layered video transmission over single hop unicast and multicast links was considered. For general multihop multicast network scenarios, it is inefficient to allocate resources independently among network links since the variation in the supported service rates among different links affects the end-to-end transport capability in the network. Cooperation among mobile devices in wireless networks has the potential to provide notable performance gains in terms of increasing the network throughput [6], extending the network coverage[9], [10], decreasing the end-user communication cost [11], and decreasing the energy consumption [12]. For example, the ICAM architecture presents an integrated cellular and ad hoc multicast scheme to increase the cellular multicast throughput through the use of mobile stations (MSs) as ad hoc relays [8]. In the UCAN architecture [7],the MSs use their WLAN interface to enhance the throughput and increase the coverage of a wireless wide area network. In [11], MSs are assumed to be connected to several wireless networks with different characteristics in terms of bandwidth, packet loss probability, and transmission cost. A near optimal solution is shown to reduce end user cost while meeting distortion and delay constraints.The advantages of cooperation among mobile devices wireless networks have been also revealed for video streaming applications [14]. For example,the CHUM architecture assumes that all mobile devices are interested in the same video content that is divided into multiple descriptions [14]; each mobile device randomly selects and pulls a video description through a cellular link and multicasts it to all members in its cooperation group which is formed in an ad hoc manner. In [16], the authors propose distributed video scheduling schemes for multiradio multihop wireless networks to minimize video distortion and ensure distortion-fairness sharing among multiple description video streams. The distortion model is constructed to provide a balance between the selfish motivation of minimizing video distortion and the global performance of minimizing network congestion.

Minimizing energy consumption in battery-operated mobile devices is essential for the development of next generation heterogeneous wireless communications systems. Enhancement schemes and communication architectures with cooperation among mobile devices to reduce energy consumption appear extensively in the literature, e.g., see [12], [13]. In [13], a cooperative network architecture is presented and experimentally evaluated to reduce energy consumption in multiradio mobile devices for video streaming applications. In [30], a comprehensive experimental study is conducted where results presented demonstrate notable energy reduction gains by collaborative downloading. The problem of resource allocation with statistical QoS guarantees and optimized energy consumption over cooperative networks with general topologies has not been tackled yet in the literature. While the work in [16] addresses optimized rate allocation and routing over cooperative wireless networks, it is fundamentally different from our work since we consider minimizing energy consumption in mobile terminals as the central objective, providing statistical delay guarantees, and capturing layered video content with QoS requirements per layer.

In this work, we develop optimized flow selection and resource allocation schemes that can provide end-to-end statistical delay bounds and minimize energy consumption for video distribution over cooperative wireless networks. The network flow for video content distribution can be any sequential multihop multicast tree forming a directed acyclic graph that spans the network topology. We model the queuing behavior of the cooperative network according to the effective capacity link layer model. Based on this model, we formulate and solve the flow resource allocation problem to minimize the total energy consumption subject to end-to-end delay bounds on each network path.

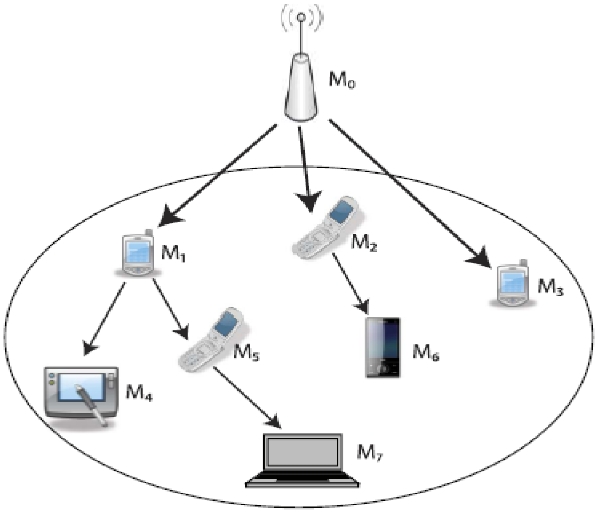
Moreover, we propose two approximation algorithms to solve the flow selection problem which involves selecting the optimal flow in terms of minimizing energy consumption. The first algorithm uses negated signal-to-noise ratios (SNR) as link weights on the complete network graph, finds the minimum spanning tree using those weights to maximize the sum rate, and performs optimal resource allocation on the flow corresponding to the obtained tree structure. Sleep scheduling algorithm which will save the unused nodes energy. By updating the optimal allocation and flow selection iteratively in each time frame according to the instantaneous channel states, the Algorithms effectively reselect the best network flow and reconfigure the service process on each link to provide optimized end-to-end transport.

The rest of this paper contained as follows: In Section 2, we review the related work. Section 3 presents our approach for Energy efficient cooperative video distribution based on sleep & prims algorithms. Finally, Section 4 concludes the paper.

II. RELATED WORK

A. *Cooperative network Model*

The proposed system model consists of a base station (BS),
denoted by M0, and K MSs M1, . . .,MK which are capable of transmitting, receiving, or relaying a scalable video bit stream. The BS is responsible for distributing the same multilayer video stream to the MSs over wireless fading channels. We define a flow as a tree of adjacent links that represents consecutive unicast/multicast transmissions. We are given a set of N candidate flows where the nth flow is defined by a set of links Fn which form a directed acyclic tree (DAG).



(a) Example network with a fixed network flow

The proposed system model consists of a base station (BS), denoted by M0, and K MSs M1,M2 . . .,MK which are capable of transmitting, receiving, or relaying a scalable video bit stream. The BS is responsible for distributing the same multilayer video stream to the MSs over wireless fading channels. We define a flow as a tree of adjacent links that represents consecutive unicast/multicast transmissions. We are given a set of N candidate flows where the nth flow is defined by a set of links Fn which form a directed acyclic tree (DAG).

Fig. (a) shows an example network with seven MSs and a fixed network flow used to explain the system model. This network flow consists of four distinct paths leading to M4, M7, M6, and M3 and traversing all MSs.

The video stream generated by the scalable video codec consists of L video layers. Each layer maintains a separate queue at each node and has specific QoS requirements according to its relevance in the decoding process. The time frame T is defined as the difference between the playback time of two video frames at the receiver, i.e., the reciprocal of the video frame rate. Within this duration T, the video frame contents corresponding to the L layers should be transmitted as per the construction of flow Fn to all K receivers to avoid playback buffer starvation.

We treat each path of the multicast tree separately by allowing the content to be streamed simultaneously (in parallel) on different paths of the network flow. This is based on the assumption that channels are readily available for all MSs in the network. Note that the number of channels required is upper bounded by the number of paths in the network. For example, the 4-path network flow in Fig. 1 requires only two channels to support the simultaneous transmission by M1 and M2.

The number of paths is typically significantly lower than the network size K, and in realistic scenarios, the network size is much less than the number of available channels in the wireless technology utilized for the short range transmissions. For instance, Bluetooth uses frequency hopping for multiple access with a carrier spacing of 1 MHz and a total bandwidth of 80 MHz.

B. Energy efficient resource allocation and flow selection

In this section, we formulate and solve the problem of hybrid unicast/multicast resource allocation over multihop cooperative networks with statistical end-to-end delay bounds. Moreover, we present a procedure for time slot adaptation and flow selection over the multihop links to obtain the optimal solution.

C. Problem Formulation

The cooperative content distribution problem can be subdivided into two components: The first component is a continuous component that involves finding the optimal allocation of time slots for all multicast transmissions along all paths of a given network flow. The second component is a combinatorial component that involves selecting the flow that minimizes energy consumption among all other flows in the network independently for each video frame. The interdependence of the two components is clear: The minimum energy consumption on any flow is determined by solving the first component, and the optimal resource allocation will take place on the network flow selected by the second component.

III. PROPOSED SCHEMES

A. Prims Minimum spanning tree flow selection

To find a suitable flow without using brute force, we should deal with network variables that are independent of the flow structure so that the flow choice is done independently and prior to resource allocation. While it is tempting to construct the spanning tree using link weights that take into account the energy consumption required to transmit on the link, this is not possible because the energy consumption requirement is a function of the resource allocation strategy and the set of multicast receivers on that link, which are both specific to the choice of the network flow. The network variable that can be readily used is the instantaneous link SNR. we construct the complete network graph with edge weights ‘K’ on the link between nodes Mk and Mk0 .We then use Prim’s algorithm [18] to obtain the minimum spanning tree.

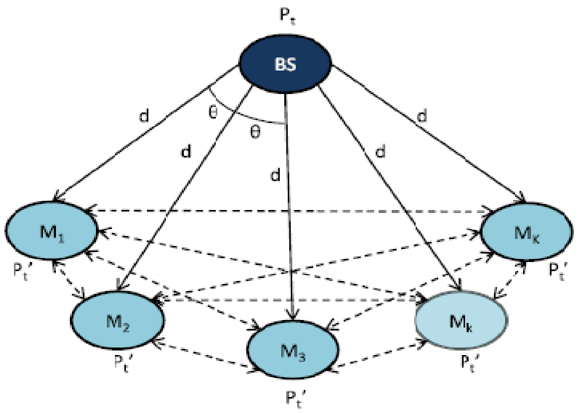


Fig. 2. Simulation model with one BS and *K* MSs.

The spanning tree is mapped to the corresponding directed acyclic graph representing the network flow, and wireless resources are allocated on that flow according to the convex problem to minimize total energy consumption. The chosen flow under this strategy maximizes the sum SNR over the network links. Using this approach, the flow selection problem is separated from the resource allocation problem. The flow selection process using Prim’s minimum spanning tree algorithm. After finding the minimum path continually apply the sleep scheduling algorithm.

B. Proposed solution-Sleep scheduling

To reduce the delay, a heuristic which maximizes the wakeup-up time in a scheduling period at three levels is used. The following is the brief description how this problem is addressed. Firstly, in a typical WSN architecture, all the nodes send their data to the sink node where the nodes near the sink nodes have to handle relatively more traffic. Sleep/wake scheduling disregards the fact that most packets go through the nodes near the sink node results in deteriorated performance. This article proposes that this delay can be minimized by considering the fact that forwarding requirement of the nodes is different according to their distance from the sink node. The sleep/wakeup schedule is directly related to the forwarding job, that is, more is the forwarding job more should be duration of wake interval. This is to minimize the schedule misses and to efficiently do the forwarding job with minimum delay. A sensor node that is near to the sink node is put into sleep state with lesser probability, and a sensor node that is away from the sink node is put into sleep state with greater probability. Consequently, the wake interval of the nodes increases as nodes come closer to the sink to handle the extra delay.

Secondly, because of the multi-hop communication paradigm of WSNs, a node's role in routing is important. Based on topology different nodes have different significance in the network. For instance, a scenario where there is only one node acting as a bridge between two distinct parts of the networks will have to forward all the traffic of one part of the network (depending upon location of the sink node). Thus, delay can be minimized by allocating sleep/wake schedule to the nodes according to the traffic load determined by the node's importance in connectivity. Giving a higher wake interval to heavily loaded nodes (connectivity critical nodes) to ensure their availability when they are needed and giving a lower wake interval to lightly loaded nodes (less connectivity critical nodes) to save their energy.

Thirdly, when an event occurs at any particular area in a WSN, generic sleep/wake cycles of the nodes remain the same regardless of the frequency of the event detection. It does not adapt itself based on frequency and location of events in terms of changing their sleep wake interval. For this problem simple ideas of temporal and spatial dependency are used. Temporal dependency in this context refers that when an event occurs in sensing area of the node in one time slot, it is likely to occur in the proceeding time slots. Thus, if the nodes can adapt and change its sleep cycle, it can reduce the delay. Similarly, local dependency refers to the fact that, if an event occurrence is reported by sensor node, there is a likelihood of event occurrence in its neighborhood nodes. Thus, nodes in the neighborhood of that node should adapt to that traffic burst and change its sleep cycle. Thus, based on temporal dependency, the wake interval of node where event occurs is increased while based on spatial dependency; the wake interval of its neighbors is increased in the next time slot. These measures can significantly reduce the delay.

(a). The proposed protocol description

In this article, sleep scheduling algorithm is proposed for event-driven sensor networks for delay-sensitive applications where events occurs rarely. The protocol consists of two main phases: the setup phase and the operation phase, as shown in Figure (b). These phases are further divided into sub-phases, as shown in Figure (c). The flow chart and the interaction among different phases sare detailed in Figure (d). Different phases are discussed in the following paragraphs.

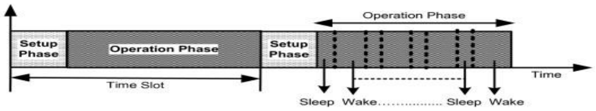


Figure (b): Life cycle of sensor network operations in SMED protocol

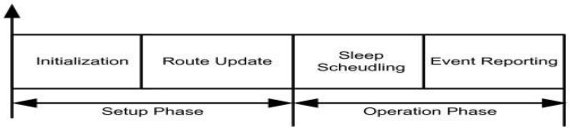


Figure (c) : SMED operations.

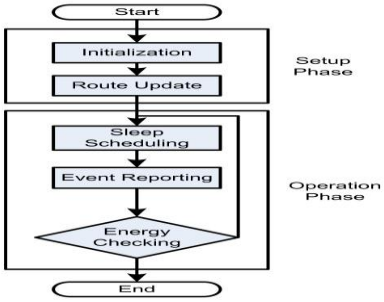


Figure (d): Flowchart of major phases and their interaction in SMED protocol.

(b). Setup phase

Setup phase is divided into two sub-phases: initialization and route update.

(1) *Initialization:* Each node computes its energy level and position in the networks. This information is used in sleep/wakeup scheduling, route update, and event reporting. Furthermore, the sink node divides the network into different regions. The sink node sends message to all the nodes in the network using three different transmission power (TP) where $TP_1 < TP_2 < TP_3$. TP_1 defines region 1, TP_2 defines region 2, and TP_3 defines region 3 as shown in Figure (e).

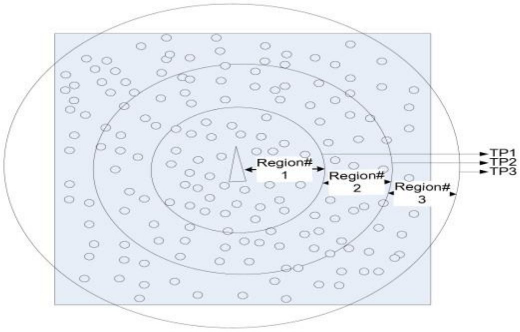


Figure (e): Dividing WSN into three regions**.**

The sink node first propagates a beacon message with transmission power TP_1. The node receiving this message will mark its region status as region 1 and will go to sleep state. Next, the sink node again propagates a control message with transmission power TP_2. As nodes in region 1 are in sleep state, thus they will not receive this message. All the other nodes receiving this message will mark their location status as region 2 and will go into the sleep state. Similarly rest of the nodes mark their region status as region 3 by receiving message TP_3.

The region information is retained by the nodes. Each node sends control message to maintain first hop neighbor information. Once a node has its neighbor information, it decides whether it is a connectivity critical node or not. To compute this, cut vertex method is used as adopted in Ref. [19]. Based on this computation, it will mark itself as a connectivity critical node; otherwise, it will mark itself as normal node.

(2) *Route update:* In the route update phase, the sink node generates a route discovery message with hop count 0 that is broadcasted throughout the network. A node upon receiving this broadcast message updates its hop count value, that is, changes its value to new value if received hop count value is less than previous hop count value, otherwise, retains the previous value. Before forwarding the route discovery message, each node increments the hop count and then broadcasts the message to nodes in its communication range. In this way, a message arrives at each node along the desired minimum cost path. Consequently, each node has a minimum hop count path to the sink node.

(c).Operation phase

This phase is sub-divided into the sleep wake scheduling and the event reporting phase.

(1) *Sleep wake scheduling:* In this phase, sleep wake scheduling is performed based on traffic loads. Traffic load of nodes differ according to region they lay, their connectivity importance, and their proximity to the event occurrence. Based on these factors, each node determines its sleep wake pattern and accordingly switches between sleep/wake states (see Figure (f)). In each sleep/wake cycle, node wakes up at set time intervals, waits for events to occur, scans the medium, and senses/receives data. The algorithm assigns three different wake interval (WT) WT_1, WT_2, and WT_3 to nodes in region 1, region 2, and region 3, respectively, where $WT_1 < WT_2 < WT_3$. The wake interval of the node is inversely proportional to the distance from the sink node, that is, lesser the distance, the greater the wake interval (see Figure (g)). It is done to make the wake interval adaptive to the traffic load of the nodes. Nodes near to the sink node have greater traffic load as compared with the nodes away from the sink node and are assigned longer wake intervals as shown in Figure (h). Also, connectivity critical nodes are assigned longer wake intervals to cater for the heavy traffic load. Algorithm 1 (see Appendix), explains how each node do the sleep/wakeup scheduling.

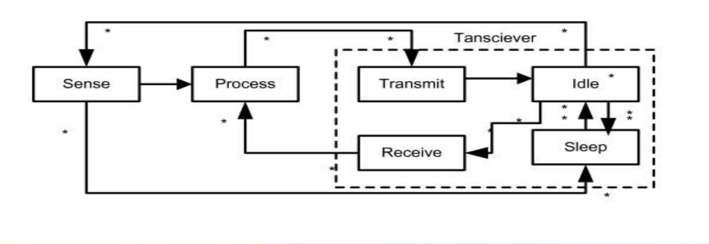


Figure (f): State transitions in SMED operations.

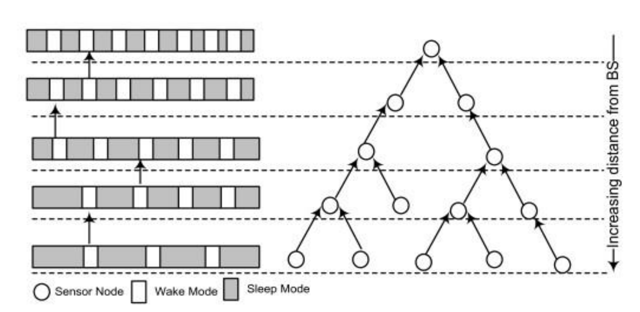


Figure (g): Assignment of different sleep/wake schedule to nodes according to their distance from BS.

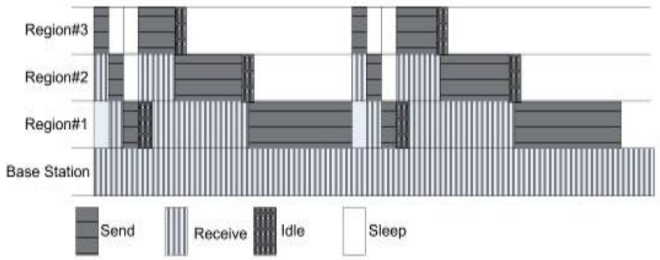


Figure (h): The path wakeup pattern of nodes in three regions**.**

(2) *Event reporting:* The event reporting phase is responsible for forwarding data to the sink node on the occurrence of event in timely manner. In this phase, data is gathered from the sensor nodes and sent to the sink node. When an event occurs in node's proximity, that node will increase its wake interval for the proceeding time slot. Furthermore, it sends message to its neighboring nodes to increase their wake interval to handle the expected traffic burst. This is because of the fact that when an event occurs in the node there is the probability of an event occurrence in the future as well (temporal dependency). Similarly if an event occurs at a node there is likelihood of occurrence of event in it neighborhood (spatial dependency). Both these case will result in expected traffic burst. Thus, the wake interval of a node where an event occurs and a node in its neighborhood is increased, to ensure the least delay in handling expected burst traffic. (see Figure (i)) explains how each node do the sleep/wakeup scheduling based on the event occurrence.

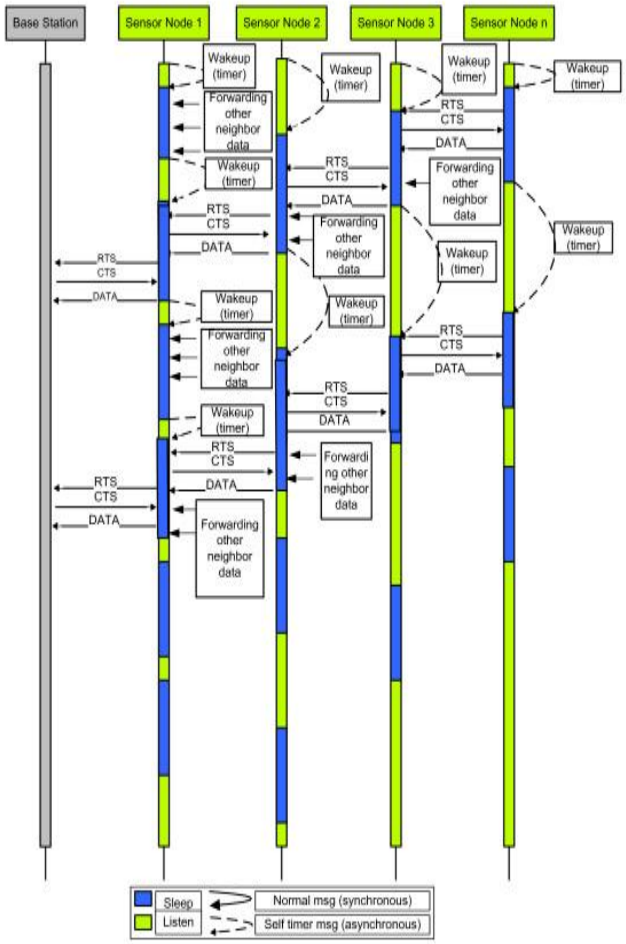


Figure (i): An event diagram for the interaction between senor node and base station during simulation.

```
Algorithm : sleep/wakeup scheduling algorithm
Input: $WI_{normal}$ the Wake Interval Normal
Output: sleep/wakeup schedule
begin
follow the determined sleep/wake schedule and sense the environment for the occurrence of the event for the specified interval defend by sleep/wake schedule and employed by self timer
if event occurs then
sset wake interval of event occurrence node to $3 \times WI_{normal}$
```

```
set wake interval of the first hop neighbors of event occurrence node to 2 × $WI_{normal}$ and send the message about the changed wake interval to the first hop neighbors
change of sleep/wake interval by the first hop neighbor upon receipt of the updated sleep/wake schedule
wait of the event occurrence node for the arrival of next scheduled slot determined by self timer before sending the sensed event data
send the data to the next hop neighbor using three way communication RTS, CTS and DATA.
go into sleep mode and wakeup in next schedule interval: a node will wake up in next schedule slot determined by updated sleep/wake schedule.
end if
end
```

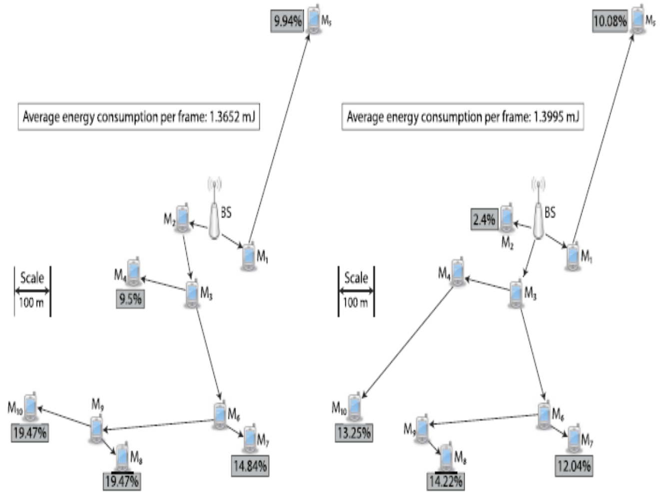
C. Embedded Prims &Sleep Algorithm

```
1.START
2.Find 'Eu' (Energy Utilization)
3.Find the most 'Eu' value from the set of nodes.
4.source->MAX(Eu)&& ACTIVE(Source)
//when heavy load is present the messages are distributed to neighbors.
//node can communicate only its awake neighbors.
5.Find Shortest--->(ACTIVE)//using prims algorithm.
6.INACTIVE-→unused nodes
7.SaveEnergy(INACTIVE)
8.Return START
```

D. Results and Analysis

The network model consists of a base station and K mobile stations M1,M2, . . .MK. We assume all K mobile stations are interested in the same content and the requirement is to select the best flow for each video frame to be delivered to all receivers reliably based on the current fading state. To gain insight into the flow selection behavior, we consider a basic model where all MSs are at a distance d from the BS, the BS link to Mk and to Mk+1 make an angle theta for all k=1 . . .K-1 as shown in Fig. 2.

We consider a large network with 10 MSs scattered randomly around the BS as shown in the configuration in figure. After running the minimum spanning tree algorithm for 10,000 training frames, we obtain the flows selected at least once to be 597. After populating the dominant set, we apply the dominant set flow selection algorithm for 10,000frames to select the best flow in terms of energy efficiency for each video frame according to the instantaneous fading state Results show that the two most dominant flows are collectively used for 38 percent of the time. These two flows are shown in Figure along with the average energy consumption per frame for each flow and the average end-to-end resource allocation on each path of the flow.



(a) The most dominant flow (1.365 mJ/frame)

(b) The second most dominant flow (1.399 mJ/frame)

..

For the best network flow, an average energy consumption of 1.3652 mJ per frame is required and the worst average end-to-end resource allocation is 19.47 percent on the path leading to M8 and M10. For the second-best network flow, an average energy consumption of 1.3995 mJ per frame is required and the worst average end-to-end resource allocation is 14.22 percent on the path leading toM8. Note that the end-to-end resource consumption is larger in the best flow than the second-best flow since it has a larger average end-to-end hop length. Furthermore, the larger multicast group size by the BS for the second-best flow limits the data rate and increases the first hop resource allocation requirement. Since the BS transmit power is typically larger than that of the MSs, this dominates the total energy consumption, and the first flow becomes a better candidate.

IV. CONCLUSION

We derived the optimal resource allocation solution for scalable video distribution over cooperative multihop networks to minimize the total energy consumption subject to end-to-end statistical delay bounds per network path. The solution is used to identify optimized energy-efficient flows consisting of hybrid unicast/multicast links to ensure reliable delivery of the video content to all requesting mobile terminals. Two low complexity approximation algorithms for flow selection are proposed and studied in terms of performance and complexity. Results demonstrate notable reductions in energy consumption sand the performance of the approximation algorithms is close to optimal for various network topologies.

REFERENCES

[1] T. Wiegand, G. Sullivan, G. Bjontegaard, "Overviewof the H.264/AVC Video Coding Standard," IEEE Trans. Circuits and Systems for Video Technology, vol. 13, no. 7, pp. 560-576, July 2003.

[2] H. Schwarz, D. Marpe, and T. Wiegand, "Overview of the Scalable Video Coding Extension of the H.264/AVC Standard," IEEE Trans. Circuits and Systems for Video Technology, vol. 17, no. 9, pp. 1103-1120, Sept. 2007.

[3] A. Kumar, D. Manjunath, and J. Kuri, Communication Networking: An Analytical Approach. Morgan Kaufmann, 2004.

[4] D. Wu and R. Negi, "Effective Capacity: A Wireless Link Model for Support of Quality of Service," IEEE Trans. Wireless Comm., vol. 2, no. 4, pp. 630-643, July 2003.

[5] Q. Du and X. Zhang, "Statistical QoS Provisionings for Wireless Unicast/Multicast of Layered Video Streams," Proc. IEEE INFOCOM, Apr. 2009.

[6] H. Wu, C. Qiao, S. De, and O. Tonguz, "Integrated Cellular and Ad Hoc Relaying Systems: iCAR," IEEE J. Selected Areas in Comm., vol. 19, no. 10, pp. 2105-2115, Oct. 2001.

[7] H. Luo, R. Ramjeey, P. Sinha, L.E. Li, and S. Lu, "UCAN: A Unified Cellular and Ad Hoc Network Architecture," Proc. ACM MobiCom, Sept. 2003.

[8] R. Bhatia, L.E. Li, H. Luo, and R. Ramjee, “ICAM: Integrated Cellular and Ad Hoc Multicast,” IEEE Trans. Mobile Computing,vol. 5, no. 8, pp. 1004-1015, Aug. 2006.

[9] Z. Dawy, S. Davidovic, and I. Oikonomidis, “Coverage and Capacity Enhancement of CDMA Cellular Systems via Multihop Transmission,” Proc. IEEE GlobeCom, Dec. 2003.

[10] J. Chen, S. Li, S.-H.G. Chan, and J. He, “WIANI: Wireless Infrastructure and Ad-Hoc Network Integration,” Proc. IEEE Int’l Conf. Comm ., May 2005.

[11] K.-J. Peng and Z. Tsai, “Distortion and Cost Controlled Video Streaming in a Heterogeneous Wireless Network Environment,” Proc. IEEE Int’l Symp. Personal, Indoor and Mobile Radio Comm., Sept. 2006.

[12] F. Fitzek and M. Katz, Cooperation in Wireless Networks: Principles and Applications. Springer, 2006.

[13] M. Ramadan, L. Zein, and Z. Dawy, “Implementation and Evaluation of Cooperative Video Streaming for Mobile Devices,” Proc. IEEE Int’l Symp. Personal, Indoor, and Mobile Radio Comm., Sept. 2008.

[14] S. Kang and M. Mutka, “A Mobile Peer-to-Peer Approach for Multimedia Content Sharing Using 3G/WLAN Dual Mode Channels,” J. Wireless Comm. and Mobile Computing, vol. 5, no. 6, pp. 633-645, Sept. 2005.

[15] Q. Zhang and Y. Zhang, “Cross-Layer Design for QoS Support in Multihop Wireless Networks,” Proc. IEEE, vol. 96, no. 1, pp. 64-76, Jan. 2008.

[16] L. Zhou, X. Wang, W. Tu, G. Muntean, and B. Geller, “Distributed Scheduling Scheme for Video Streaming over Multi-Channel Multi-Radio Multi-Hop Wireless Networks,” IEEE J. Selected Areas in Comm., vol. 28, no. 3, pp. 409-419, Apr. 2010.

[17] G. Ananthanarayanan, V. Padmanabhan, and L. Ravindranath, “COMBINE: Leveraging the Power of Wireless Peers through Collaborative Downloading,” Proc. Int’l Conf. Mobile Systems, Applications, and Services (MobiSys ’07), June 2007.

[18] T. Cormen, C. Leiserson, R. Rivest, and C. Stein, Introduction to Algorithms. McGraw-Hill: MIT Press, 2001.

[19] AA Abbasi, K Akkaya, M Younis, A distributed connectivity restoration algorithm in wireless sensor and actor networks. 32nd IEEE Conference on Local Computer Networks 2007, LCN 2007 (2007).