International Journal of Computing and Digital Systems
ISSN (2210-142X)
Int. J. Com. Sys. Volume 10, No. 1 (Jan, 2021)
http://dx.doi.org/10.12785/ijcds/100121

Quality-Aware Resource Allocation Protocol for Improved WiMax Video Surveillance Systems

Nedal Ababneh

Department of Information Security Engineering Technology (ISET), Abu Dhabi Polytechnic, P.O. Box 111499, Abu Dhabi, UAE

Received 18th Aug. 2020, Revised 12th Nov. 2020, Accepted 2nd Dec. 2020, Published Jan. 2021

Abstract: In surveillance systems, video quality must be kept above a certain limit to be able to perceive the contents. In the standard system, when the overall throughput drops, all cameras data rate, regardless their importance, equally drops and thus the utility of the whole video surveillance system drops. In crucial conditions, available system throughput may not be adequate to accommodate all cameras streaming video data. In such situations, some low priority camera(s) may put offline to improve the utility of the video surveillance system. In this paper, we propose a Joint Routing and Rate Assignment Protocol, named JRRA, for improving the performance of WiMAX network in terms of utilization and throughput. The JRRA protocol constructs the highest end-to-end residual capacity path and ensures best data rates are allocated for maximizing network throughput, capacity and guarantees fairness as well. The problem also formulated as Mixed Integer Linear Program (MILP) that maximizes the system utility while satisfies the Quality of Service (QoS) requirements. The performance of our protocol was compared to other existing work in the literature, and proves that it closes the gap from the theoretical optimal solution.

Keywords: WiMAX Mesh Network; Resource Allocation; Utility Maximization; Tree Construction; Bandwidth Assignment.

1. Introduction

Wireless surveillance systems are expected to provide a wide range of services to a large number of users in smart in different contexts [1], [2]. Advanced radio resource allocation strategies thus arise not only to perform efficient resource allocation, but also to provide fairness among nodes and maximize system usefulness. On the other hand, the perceived video quality is becoming one of the main metrics within the allocation strategy design. This paper provides a comprehension overview of what is QoS and the evolution of wireless resource allocation techniques. It highlights the application/service of the different strategies exist in the literature, in addition to the considered parameters for QoS maximization [3]. This works helps researchers who are interested in exploring principals and concepts of QoS-oriented wireless resource allocation.

IEEE 802.16 standard, termed WiMAX (Worldwide Interoperability for Microwave Access), was introduced in 2004 [4] as a wireless solution to meet the rapidly increasing demand for data bandwidth at the radio access. In particular, it is known for its long communication rang, high end-to-end system throughput, and guaranteed data transmission. In this research, we consider a WiMAX system architecture demonstrated in Fig. 1, where real-time video streams collected at different places need to be gathered at some points, called Collection Points (CPs), which are connected to the Internet or a fixed network. The video data then forwarded through the fixed network by CPs to a Control Center (CC). As it is unlikely possible for all cameras to reach a CP directly, multi-hop WiMAX routing are required to forward data streams to the CPs. This architecture may have many practical applications, one good example of such applications is video surveillance in areas where traditional wired networks are not considered practical solution. One key design issue for such application is that, the received Data Rates (DR) must not drop below a given threshold limit for the content to be viewable to the security experts [5]. The communication path construction in the network is considered a critical task to guarantee efficient radio utilization in WiMAX networks and, thus, maximizing network throughput. Having said this, a tree-based routing algorithm can allow traffic aggregation and guarantee

E-mail: Nedal.Ababneh@adpoly.ac.ae

optimal usage of the finite available bandwidth. Hence, a spanning tree that is rooted at each CP can be used for traffic streaming, wherein intermediate relays aggregate and forward the generated traffic. Each intermediate node associates itself to only one tree (a parent) at a given time, and can re-attach itself to another available tree (i.e. towards another CP) for failure recovery [6].

The problem of guaranteed transmission of video stream in WiMAX mesh networks context for video surveillance purposes is tackled in this work. The problem includes: (1) Constructing efficient Routing Trees (RTs), and (2) Selecting the best bandwidth and data rate for each node to maximize utilization and accept as many video flows as possible that meet Quality of Service (QoS) requirements. The network and physical layers QoS constraints are translated into lower/upper bound on node data rate, an upper bound on uplink capacity and an upper bound on channel capacity at each intermediate node in the tree. In this paper, we describe and evaluate a novel cross-layer optimization protocol for video streaming in the context of WiMAX networks. Followings are the major research contributions of this work:

- The joint routing and rate assignment optimization problem is formally defined and a Mixed Integer Linear Program (MILP) formulation is presented. Obviously, optimal results are used for benchmarking purposes as they are not possible for large-scale network instances.
- We propose a Joint Routing and Rate Assignment protocol, termed JRRA[1], which consists of: (1) A fully distributed spanning tree-based and bandwidth-aware routing algorithm, and (2) An effective rate assignment algorithm that take into account QoS requirements. The JRRA protocol assigns the resources among nodes according to their needs and priorities in a fair way.
- We study the performance of the proposed solution on a wide range of application scenarios, proving that it incurs to a promising results.

The terms camera, node, and relay are used interchangeably in this paper. The remainder of this work, is structured as follows. In Section 2, we discuss the related work, which highlights the differences between existing solutions and our proposed solution. In Section 3, we present the optimal solution of the problem using a MILP. The design of JRRA protocol is discussed in Section 4 , which is then evaluated in Section 5. Section 6 wraps up our contribution.

2. Related Work

To obtain the best feasible network throughput, the routing metrics applied in the routing protocol are very critical. The routing metric, introduced in [8], is designed to attain factors affecting the performance of the network. In this work, it is defined as the utility and network throughput. Hop-count is widely used in many routing protocols as a performance metric to select the route in

[1]A preliminary version of this solution appeared in [7]. Here we present more design details with more comprehensive new set of experiments and performance analysis of the solution.

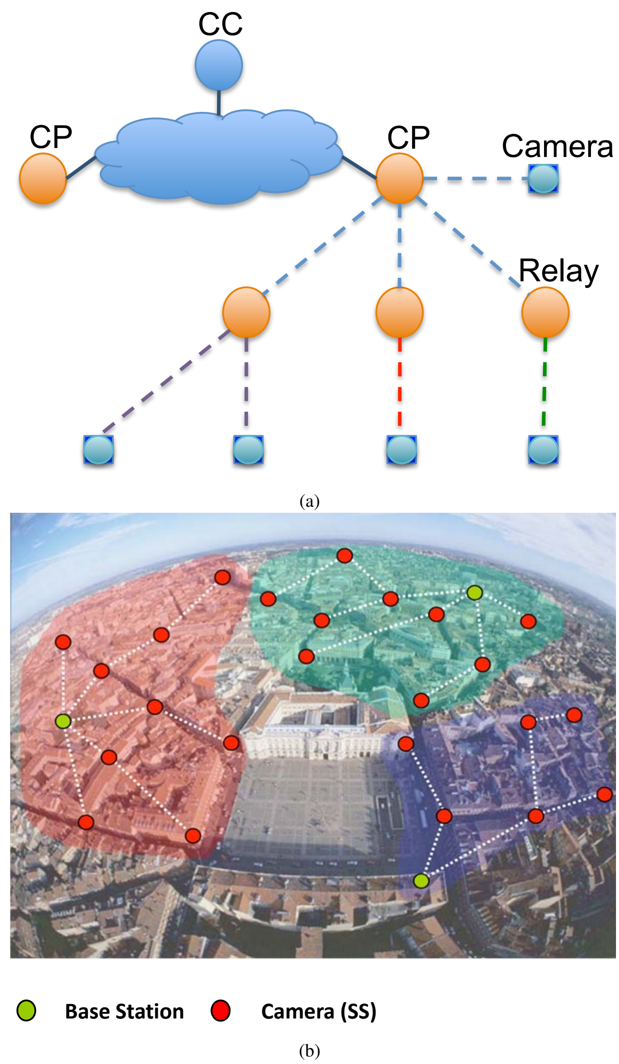


Figure 1. The WiMAX network architecture.

multi-hop networks [9]. The hop-count from a source node to a given BS is determined by network topology and is thus mostly static, and thus, enables rapid convergence of the algorithm. However, shortest path RT may not necessary maximize network throughput as links on the shortest path may not have a good quality [10]–[12]. This is because the shortest path between the source and destination may correspond to longer communication links to cover the same distance, which results in poor quality links with low DRs [13].

Many works have previously addressed different routing metrics for constructing routes with high end-to-end throughput in wireless networks in the literature. For example, Couto et al. [14] proposed ETX (expected transmission count), a new metric to find high-throughput paths on multi-hop wireless networks (802.11b), that minimizes the expected total number of packet transmissions (including retransmissions) required to deliver a packet to its ultimate destination successfully. In opposition to the hop-count metric, ETX incorporates link loss ratios, asymmetry in loss ratios between the two directions, and interference among successive links. Yet, ETX does not perform efficiently for large packet sizes. Draves et al. introduces a different routing metric in [15], named weighted cumulative expected transmission time (WCETT). This metric (WCETT) allow both link quality metric and the minimum hop-count, and attains good balanve between delay and throughput. The authors presume that all radios on each node are tuned to non-interfering channels with the assignment changing infrequently. Wei et al. Another new metric was proposed based on interference degree for tree construction to improve the throughput of 802.16 mesh networks [16]. But it does not take into account the bandwidth request of SSs when constructing routing paths.

In [17], the authors reported the latest findings and explore concepts and challenges related to managing Quality of Experience (QoE) for multimedia services. They discuss QoE management in ongoing developments context, e.g., softwarized networks, machine learning and big data analytics, as well as augmented and virtual reality. they also highlight the need for new and creative QoE management strategies. In [1], the authors surveyed state-of-the-art radio resource allocation techniques in heterogeneous networks context. They focus on the joint optimization of radio resource management with other schemes. These resource allocation techniques were then categorized according to considered optimization metrics and further, they were analyzed and compared qualitatively. Also, they present schemes complexity analysis in terms of implementation and speed. Authors in [3] presented a survey of QoE management techniques that have been studied recently categorized into three main categories. Firstly, QoE-aware/driven schemes using Software Defined Networks (SDN) and Network Function Virtualization (NFV). Secondly, QoE-aware/driven schemes for adaptive streaming over emerging architectures e.g., multi-access edge computing, cloud/fog computing, and information-centric networking, and finally, extended QoE management schemes in trending domains e.g., virtual reality and video gaming applications. They highlight a number of future challenges in different contexts and discuss future research directions. Furthermore, numerous research efforts have studied WiMAX in the context of video streaming applications. Geetha *et al.* [18] presented a dynamic bandwidth allocation mechanism to attain fair and efficient allocation. To obtain fair bandwidth allocation among the competing traffic classes, a dynamic weight assignment mechanism is presented. Performance of the weight assignment mechanism is analytically evaluated using the GSPN model. Another research effort was conducted in [19], the authors evaluated Medium Access Control (MAC) layer performance by scaling video content over multiple connections based on feedback of the available transmission bandwidth. The authors in [5] proposed a solution to enhance the utility gain of a live video traffic from cameras deployed in a high mobility public transport. The authors did not consider the priorities of the cameras, and simply assumed all cameras have the same level of importance.

To the best of our knowledge, the design of optimal joint routing and rate assignment that can maximize the overall revenue while guaranteeing the QoS for WiMAX mesh networks has not been addressed in previous work. This paper describes and analyzes a novel cross-layer optimization design for video streaming in WiMAX that offers the required QoS for video data. WiMAX is considered a promising technology, however, the available bandwidth can be insufficient to serve a numerous number of video flows from all source cameras deployed in a given area. In the slandered systems as above, when the available throughput is low, DR for all cameras falls equally and the utility of the whole video surveillance system decreases dramatically. In the proposed protocol, we anticipate the utility for all cameras and turn off some low utility ones to maintain high quality of the video surveillance system.

3. Optimal Solution

In this section, we present our optimal solution.

A. Notations and Definitions

The network is represented as undirected graph $G = (V, E)$, where V is the set of vertices that includes a group of relay nodes, V_N, and a group of CPs, V_{CP}. E denotes the set of edges i.e. edge $(v_i, v_j) \in E$ iff v_i, v_j are within the communication range of each other. Each edge (v_i, v_j) has a physical capacity L_{ij}, which represents the maximum amount of traffic that can pass through this particular link. At any given time, a node may either transmit or listen to a single wireless channel. For simplicity reason , we assume that each relay node $v \in V_N$ is equipped with one camera. where the model can deal with an arbitrary number of cameras. All nodes in the network are assumed to work on the same fixed transmission power. $N(v)$, is the set of nodes of neighbor nodes of node v. Thus, a bidirectional wireless link exists between v and every node $u \in N(v) - \{v\}$, which is represented as an edge$(u, v) \in E$. $\delta(v)$denotes the number of neighbors of a vertex v, the degree of v. The resulting trees (RTs) $T = (V', E')$ is a subgraph of G, where E' represents the communication links , and V' is the set of relays and CPs included in the computed tree(s).

A *utility* function is proposed to assess the relative importance of cameras and the gain when included (accepted) in the tree as in our previous work [7]. U_i denotes the utility ofv_i video stream. This utility depends on the minimum acceptable video rate W_{min} and the maximal desired DR W_{max}. It also depends on P_i, which identify the priority associated with each camera (e.g., either high or low). This value can be pre-assigned based on the geographic location of the cameras and the captured data, and can be dynamically changed by an operator. Utility evaluation in the network is demonstrated in Fig. 2. We use a simple step-wise linear function. Let r_i be the current DR allocated to camera v_i, then $U_i = 0$ whenever $r_i < W_{min}$ as the flow cannot be properly interpreted at the control center. In other words, the video streaming is useless and should be stopped to conserve system resources. Note that, video data can be stored locally, if possible, and will be retrieved later when the bandwidth permit. When $r_i = W_{min}$, the utility reaches a value $P_i U_{min}$ and then smoothly increases with r_i towards $P_i U_{max}$ for $r_i = W_{max}$. Note that, by construction, we must have $r_i \leq W_{max}$.

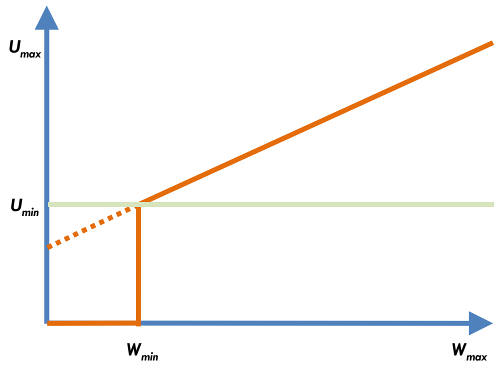


Figure 2. Example utility function.

B. Mixed Integer Linear Program Formulation

Let x_{ij} be a 0-1 integer variable for each $(v_i, v_j) \in E$ such that $x_{ij} = 1$ if the edge (v_i, v_j) is included in E' (i.e., the final RT). Also, let z_i be a 0-1 integer variable for each camera $v_i \in V_S$, such that $z_i = 1$ if the camera v_i is accepted as a traffic source in the resulting RT (i.e., $v_i \in V'_N$). Let r_i be a positive real variable for each $v_i \in V_N$, representing the effective DR of v_i, such that $r_i = 0$ if v_i is not included in the resulting tree (i.e., $z_i = 0$). Furthermore, let y_{ij} be a positive integer variable for each edge $(v_i, v_j) \in E'$, showing the amount of data transmitted from node v_i to node v_j (i.e., uplink effective DR), where the receiver could be a CP node. The MILP for the RT construction and rate assignment problem can thus be stated as follows:

Objective function:

$$max \sum_{i \in V_S} z \cdot P_i \cdot U_{min} + z_i \cdot P_i \cdot (r_i - R_{min}) \cdot U_{step}$$

The first term of the utility function is the minimum utility for each camera in the network, and the second term denotes the utility evolution with rate. Multiplying the second term by U_{step} (which is equal to $(U_{max} - U_{min})/(W_{max} - W_{min})$ in this scenario) ensures utility evolution with rate. Also, multiplying the first and second terms by z_i guarantees the consideration of the included vertices cameras in the resulting tree(s) only. Note that, each accepted camera $v_i \in V'_N$ is assigned rate $r_i \geqslant R_{min}$ from constraint 8 below. The coefficient U_{min} is the minimum utility of each accepted camera v_i, and must be set to any positive value greater than zero (i.e., 1 in this case).

Constraints:

$$x_{ij} \leqslant y_{ij} \leqslant L_{ij} \cdot x_{ij}, \forall i \in V_N, \forall j \in V : (i, j) \in E \quad (1)$$

$$\sum_{\forall j \in V_N : (j,i) \in E} y_{ji} \leqslant C_i, \forall i \in V \quad (2)$$

$$\sum_{\forall j \in V : (i,j) \in E} y_{ij} - \sum_{\forall j \in V : (j,i) \in E} y_{ji} = r_i \cdot W_{max}, \forall i \in V_N \quad (3)$$

$$\sum_{\forall j \in V : (i,j) \in E} x_{ij} \leqslant 1, \forall i \in V_N \quad (4)$$

$$\sum_{\forall j \in V : (i,j) \in E} x_{ij} = 0, \forall i \in V_{CP} \quad (5)$$

$$\sum_{\forall j \in V : (i,j) \in E} y_{ij} = 0, \forall i \in V_{CP} \quad (6)$$

$$z_i \geqslant r_i, \forall i \in V_N \quad (7)$$

$$r_i \geqslant R_{min} \cdot z_i, \forall i \in V_N \quad (8)$$

Inequality (1) ensures that the uplink effective rate of each included edge in the resulting tree is bounded by the physical link capacity. Constraint (2) provides an upper bound on the relay load constraint. Constrain (3) is for flow conservation. Constraints (4) guarantees that no camera has more than one parent as in [20]. Constraint (5) implies that a CP has no parent. Constraint (6) ensures that a CP has no uplink traffic. Constraint (7) denotes that camera DR is assigned to accepted cameras in the RT only, i.e., not included camera in the resulting tree has rate equal to zero. Finally, constraint (8) guarantees that assigned rate$r_i \geqslant R_{min}$ for accepted camera v_i, this is to ensure the minimum acceptable QoS constraints..

In the following, we discuss our algorithmic solution for the problem. We define new performance metrics for RT construction followed by a near optimal rate assignment algorithm that ensures the QoS constraints.

4. Algorithmic Solution

This section presents the design and implementation of the JRRA protocol.

A. Tree-Based Routing

We present a capacity-aware routing algorithm that maximize throughput capacity while constructing routing paths. The ultimate goal is to select the route with highest end-to-end residual capacity. This algorithm calculates the best capacity on the set of possible routes, and chooses the route that gives the highest data rate. The algorithm is demonstrated in Alg. (1).

Each node connected to a CP periodically broadcasts ADV messages to its neighbors. These messages are used by neighbors to compute the α values and choose their parent nodes. The node i chooses the parent node, denoted by $prnt(i)$, that maximizes its effective uplink capacity (DR) as described in Alg. 1.To join a parent node v_j, a node v_i sends a JOIN message to node v_j. When v_j receives this message, it adds v_i to its list of children denoted by $Child(j)$, and sends back an ACCEPT message to v_i. As a result, it is possible for a neighbor v_k which depends on the same parent (v_j) to find an alternative branch with a better route to a CP.

In this case, node v_k attempts to join the alternative branch (JOIN/ACCEPT procedure), if successful, v_k leaves its current parent (i.e., branch) by sending a LEAVE message to v_j. The routing tables are updated in the nodes by exchanging additional messages, namely RT_ADD and RT_DEL. The former is used upwards

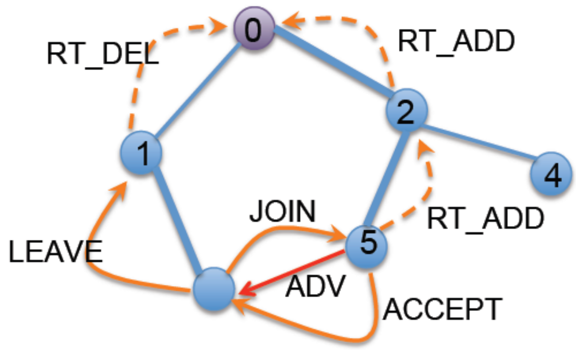


Figure 3. Tree construction example.

from leaves to the CP when a new node joins a branch, while the latter deletes a node from a branch after the reception of a LEAVE message. The tree structure is rebroadcasted in the ADVERTISE messages. These procedures are demonstrated in Fig. 3.

Algorithm 1 Capacity aware routing

Input: $prnt(i)$, the current parent of the node i. $prnt(i) = \phi$ if the node is joining the mesh. $UplinkCap(i)$, the current uplink capacity. $UplinkCap(i) = 0$ if the node is joining the mesh.

```
procedure ParentSelection(prnt(i),UplinkCap(i))
    for all j ∈ CN do
        Child(j) ← Child(j) ∪ i {add i to j's list of children }
        α_j ← UplinkCap(j)/ |Child(j) |
        if α_j > UplinkCap(i) then
            prnt(i) ← j
            UplinkCap(i) ← α_j
        else
            Child(j) ← Child(j) − i {remove i from j's list of children }
        end if
    end for
    send(j, JOIN-MSG)
return prnt(i)
end procedure
```

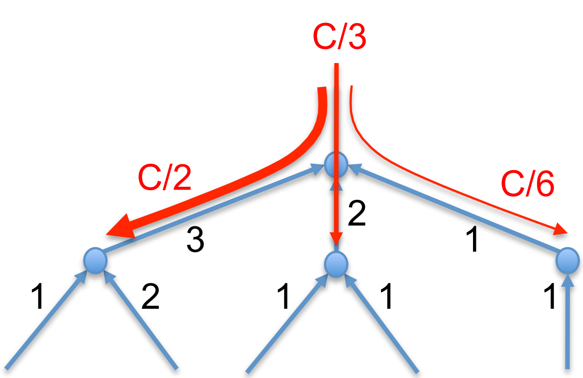


Figure 4. Basic principle of the rate assignment algorithm.

B. Rate Assignment

We first present the algorithm for a single level of hierarchy as illustrated in Fig. 4. The algorithm consists of 1) computing the number of flows that pass through each branch of the tree and then 2) to assign a capacity to each branch that is proportional to this quantity. Here, there are 6 flows in the tree with a total uplink capacity of C. $\frac{C}{2}$capacity is assigned to left branch that delivers 3 flows, while the middle branch gets $\frac{C}{3}$ as it has 2 flows. After, we verify if the allocated bandwidth is large enough to accommodate the video flows (i.e., $> W_{min}$). If this is not the case, the number of flows that passes through the branch is reset to zero and the capacity assigned to this branch is released. It means that the cameras (flows) that pass through this branch will have to be put offline in this critical situation where there is not enough available bandwidth (Of course, we expect that an alarm will be displayed in order for the human operator to be aware of this situation. The configuration of priorities of the different cameras can be changed accordingly). The capacity of this branch is redistributed to the neighboring branches. For instance, in Fig. 4, imagine that $\frac{C}{6} < W_{min}$ so that the video flow of the right branch has to be turned off. The flow counts are modified accordingly and the neighboring branches are now assigned $\frac{3}{5}C$ and $\frac{2}{5}C$ respectively. Similarly, these capacity pre-assignment must also be compared to the physical capacity of each branches (i.e. L_{ij}). When the assigned amount of capacity is too large to be accommodated by the branch, it is then adjusted and the remaining capacity is assigned to the neighboring branches. This procedure is repeated from the CPs (roots) towards the leaves. The remaining bandwidth is then shared by the lower level of priority by a new instance of the algorithm and so on.

```
▷Ensure consistent link capacity along the path
for each level h ← 1 to TreeDepth − 1 do
    for each node i such that H(i) ← h do
        if UplinkCap(i) > UplinkCap(prnt(i)) then
            UplinkCap(i) ← UplinkCap(prnt(i))
        end if
    end for
end for
```

Figure 5. Pseudo-Code for ensuring consistent link capacity step.

The algorithm runs in a centralized manner at each CP . The three steps of the algorithm are then described as follows:

1) Initialization Step

The algorithm starts with initialization of the variables. More precisely, the number of flows with priority p (p is either high or low in this paper) passing through node v_i is denoted by F_i^p. These values (i.e., F_i^p) can be calculated by browsing the tree in opposite direction, starting from the leaves and going up to the root (CP) (i.e., leaf-to-root manner), $F_i^p = \sum_{j \in Child(i)} F_j^p$. The parent node of a node v_i is denoted by $prnt(i)$. Consequently, the set $Child(i)$ represents the set of nodes which are directly connected to node i. $H(i)$ denotes the hierarchical level of node i in the tree. (e.g., $H(CP) = 0$, $H(i) = 1$ for a node i that is directly connected to a CP, etc.).The capacity allocated to node v_i is denoted by $UplinkCap(i)$. It corresponds to the bit rate available for this node at the uplink (how much traffic it can relay including its own generated data). This value is bounded by the cell capacity C at each node (and the CPs) as well as to the physical link capacity $L_{i,prnt(i)}$. The $UplinkCap(i)$

is dynamically updated to ensure the accuracy of the algorithm based on the available capacity upstream and the number of high priority video flows. Once initialized, these $UplinkCap$ values should be coherent. In fact, the available $UplinkCap$ of a node can be greater than of the nodes in the path to the CP. Figure 5 demonstrates the procedure used to ensure a node is assigned $UplinkCap$ not greater than the $UplinkCap$ of the nodes in its path towards the CP.

2) Uplink Capacity Assignment Step

The main capacity allocation procedure, demonstrated in Fig. 6, is executed (once for each priority level (high or low), starting with nodes with high priority value of p). The DR of the nodes of priority p can then be

---

▷Assign uplink capacity directly proportional to Flow count
for each level $h \leftarrow 1$ to $TreeDepth - 1$ **do**
  for each node i such that $H(i) \leftarrow h$ and $F_i^p > 0$ **do**
    $UplinkCap(i) \leftarrow (F_i^p / F_{prnt(i)}^p) \times UplinkCap(prnt(i))$
    ▷Check physical link capacity constraints
    if $UplinkCap(i) > L_{i,prnt(i)}$ **then**
      $UplinkCap(i) \leftarrow L_{i,prnt(i)}$
    end if
    ▷If not enough bandwidth, put node (and its branch) offline
    if $UplinkCap(i) < W_{min}^p$ **then**
      $F_i^p \leftarrow 0$
      $UplinkCap \leftarrow 0$
      $r_i \leftarrow 0$
      ▷Update Flows for $prnt(i)$
      $F_{prnt(i)}^p \leftarrow F_{prnt(i)}^p - F_i^p$
      for each node $j \in Child(i)$ **do**
        $F_j^p \leftarrow 0$
      end for
      ▷Re-assign bandwidth to neighbors as Flow count has changed
      for all $j \in Child(prnt(i))$ **do**
        $UplinkCap(j) \leftarrow (F_j^p / F_{prnt(i)}^p) \times UplinkCap(prnt(i))$
        ▷Check physical link capacity constraints (again)
        if $UplinkCap(i) > L_{i,prnt(i)}$ **then**
          $UplinkCap(i) \leftarrow L_{i,prnt(i)}$
        end if
      end for
    end if
  end for
end for

Figure 6. Pseudo-Code for assigning uplink capacity step.

determined. Starting from leaf nodes, a leaf node i will be assigned rate $r_i = UplinkCap(i)$, such that the QoS requirements are met. The node updates its incoming and outgoing traffic ($inTraffic$ and $outTraffic$, respectively) variables to allow accurate rate allocation for upstream nodes. For leaf node i, $inTraffic = 0$ and $outTraffic = r_i$. Nodes in the upper level will then compute their $inTraffic$, and their rates will be calculated as follows: $r_j = UplinkCap(j) - inTraffic(j)$. The rate assignment process will recursively continue level by level until the CP.

3) Rate Assignment Improvement Step

After assigning DRs as described in the previous steps, we check for any residual available bandwidth at each node. For instance, a leaf node might be allocated an $UplinkCap > W_{max}$, in this case $UplinkCap - W_{max}$ extra bandwidth is available. In our algorithm, such bandwidth will be re-allocated to nodes without violating QoS constraints. Checking for extra bandwidth process commence in leaf-to-root manner, where residual bandwidth at node i is computed as $UplinkCap(i) - (r_i + inTraffic(i))$ and will be moved to the CP to be allocated to other nodes where possible. This procedure will be repeated recursively until there is no extra bandwidth available in the network or the given constraints (QoS) are not permitting any further bandwidth allocation.

5. Performance Evaluation

To evaluate the performance of our proposed protocol, we ran an extensive set of experiments using a VC++ coded simulator. We compare the performance of our proposals to the optimal solution presented in (3-B). We solve the MILP using a commercial version of CPLEX and AMPL. Table I highlights CPU run times in second for finding optimal solutions.

TABLE I. CPU times for solving the MILP.

$\|V\|$	$\|E\|$	*Degree*	Time (sec)
20	90	4	0.2
25	175	7	0.5
30	280	9	3
35	420	11	10
40	530	13	54
45	600	14	72
50	760	15	80

We compare our routing algorithm to two other routing algorithms, *path-capacity* routing (termed as JRRA-PC) and *shortest-path* routing (termed as JRRA-SP). The former works by calculating the best path capacity spanning tree, it represents the best physical capacity of the path. Path capacity assumes that the bottleneck of a path can be constituent link on the path. The latter enables a node to reach the wired network using the minimum number of hops. Nothing is done to balance out network load. The results are an average of five different runs using random topologies, the simulation parameters are summarized in Table II.

TABLE II. Simulation parameters.

Parameter	Value
Terrain	1000 x 1000 m^2
Transmission range, R_T	200 m
Number of CPs	3
Cell Capacity, C	20
Priority P	1
W_{min}, R_{min}	768 Kbps
W_{max}, R_{max}	4608 Kbps
Link Capacity	2, 5 or 8 Mbps
U_{min}	1
U_{step}	1/5

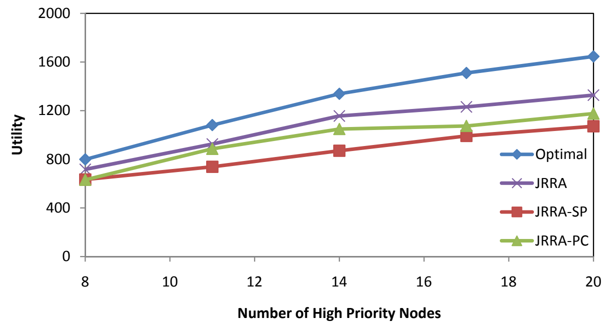


Figure 7. Network utility vs. number of HP nodes.

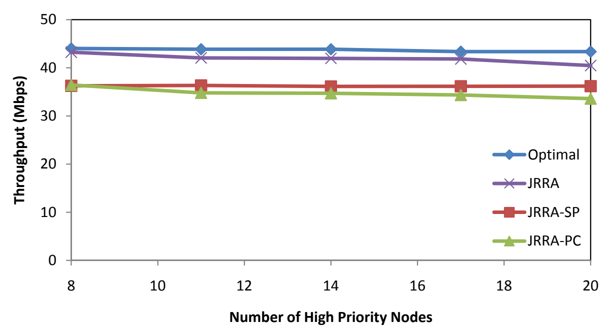
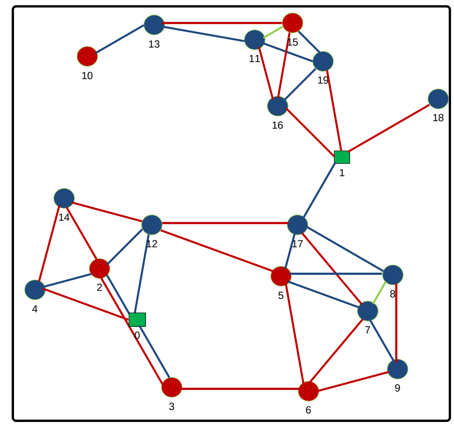


Figure 8. Network throughput vs. number of HP nodes.

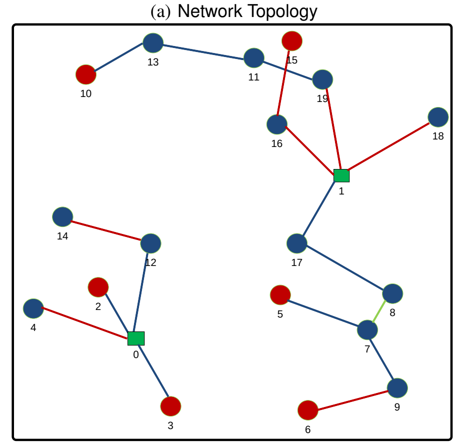
A. *Number of High Priority Nodes Effect*

In order to study the effect of number of high priority (HP) nodes (cameras) on the network performance, the random graphs with average node degree of 5 is considered. The number of HP nodes is varied from 8 to 20. Other settings are similar to the above.

Utility and Throughput: It is obvious from Fig. 7 that all protocols achieve a smooth utility increase with the increase of HP nodes. This is due to the fact that more HP nodes deployed, all proposed protocols will try to accommodate as many of them as possible at the best possible DR, which yield a better utility. Figure 8 shows the throughput with respect to the number of HP nodes in the network. Regardless the HP nodes number is, it shows the throughput of all protocols remains nearly constant. This is because all protocols first try to allocate the highest rate to the HP nodes, after, if more bandwidth still available they will allocate it to low priority nodes, and thus, the whole network will attain the same throughput regardless the priority and importance of the nodes. It is interesting to note that our protocol consistently yields a better performance than shortest-path and path-capacity routing. Although sometimes the shortest-path routing does not necessarily indicate the higher network throughput, it performs similar to JRRA-PC in this experiment. As an example of evaluation results, when two CPs are deployed, the corresponding WiMAX optimal RT is shown in Fig. 9. From Fig. 9, we realize that more number of hops are obtained by the optimal solution. This is because shorter links can support higher DRs. It is often possible to obtain higher throughput by multi-hopping since higher DRs are used. As the distance increases, more robust burst



(a) Network Topology



(b) Optimal RT

Figure 9. Example of WiMAX optimal RT construction. A scenario with 20 nodes placed randomly on a square field of 1000 m side length, and a radio range of 200 m. A red filled circle represents a HP camera, a blue filled circle represents a regular node and a green filled square represents a Collection Point (CP). Solid line indicates communication link. Different link colors represent different capacity levels i.e., green:8 Mbps, blue:5 Mbps and red: 2 Mbps. Node 6 is connected to CP #1 through 5 hops, while there is a possible path to CP #0 with 2 hops length only, this is because CP #1 provides better bandwidth.

profiles (modulation and coding techniques) are needed to reduce bit error rate which results in lower DR. For instance, 64 QAM3/4 can ensure almost 11 Mbps for 1.5 km. QPSK1/2 can offer 2 Mbps at 5 km [13].

Number of Accepted Traffic Sources: Figure 10 shows how well the JRRA protocol performs compared to the optimal solution in terms of number of accepted traffic sources (i.e., cameras) in the resulting RTs. As can be seen from the graphs, the JRRA reacts smoothly and consistently as the number of HP nodes increases. It is clear that, as the number of HP nodes increased, all protocols experience an improve in the number of accepted cameras. In other words, as we increase the number HP nodes deployed in the network, the proposed solution will try to accept as many of them as possible with best DR as demonstrated further in Fig. 11.

Received Video Data Quality: The influence of number of HP nodes deployed on the data quality received from the accepted HP nodes is also evaluated. Figures 11(a) to (d) show the impact of different number of HP nodes on the streaming data quality coming from the accepted HP nodes, while the video data is the actual information transferred across the wireless links. We classified the data quality based on the allocated DR into three levels: poor (768 - 2048 Kbps), good (2049 - 3328 Kbps) and excellent (3329 - 4608 Kbps). From the figures, we can see that the percentage of HP nodes accepted at better quality, and thus higher utility, decreases with the the number of HP nodes in all solutions. The optimal solution slightly outperforms our proposal, this is because more routes are available in the network with possibly better capacity, and the optimal solution provided by the MILP is able to select a better capacity path. As a result, the best DRs are allocated to HP cameras. However, it is apparent that the JRRA protocol is able to achieve near optimal results with fair distribution of the available bandwidth across the accepted cameras followed by JRRA-PC and JRRA-SP, respectively. It is important to note that although JRRA accepts more HP cameras (i.e., flows) than JRRA-PC and JRRA-SP, as demonstrated in Fig. 10, it still outperforms them in term of received video quality.

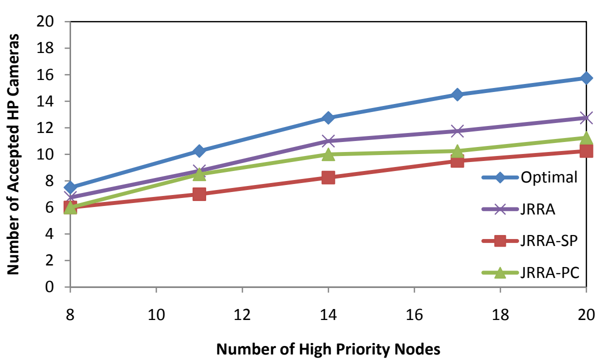
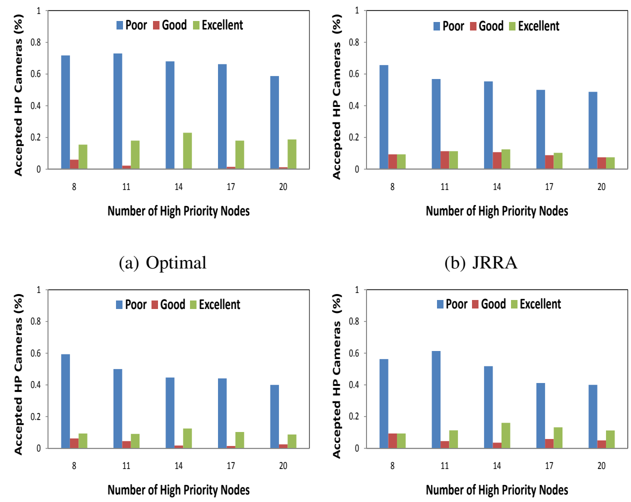


Figure 10. Number of accepted HP cameras vs. number of HP nodes.

B. Average Node Degree Effect

We control average node degree by adjusting node's transmission range, we vary the average node degree from 3 to 7 in this experiment. The fraction of HP cameras to the total number of cameras is set as $\alpha = 30\%$.

Utility and Throughput: Figures 12 and 13 plot the utility and throughput, respectively, as a function of average node degree. It is evident that all protocols experience performance increase with the increase in node degree [21] [22]. This is due to the fact that more routing choices are available for nodes when the number of nodes increases. The proposed protocol is good at choosing advantageous route when the node degree increases. The proposed protocol is still able to achieve near optimal results with the increased node degree , indicating that JRRA is scalable to high node density. This is because JRRA helps to make a decision whether to put camera(s) offline based on the estimated video transmission rate and calculated utility from various camera sources. JRRA with path-capacity routing (JRRA-PC) attains a more



(a) Optimal (b) JRRA

(c) JRRA-SP (d) JRRA-PC

Figure 11. Received video quality of accepted HP nodes vs. number of HP nodes.

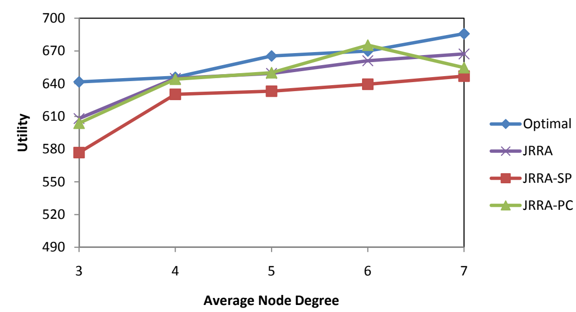


Figure 12. Network utility vs. average node degree (number of neighbors).

or less equal utility to JRRA. Nevertheless, among all routing algorithms, the proposed solution JRRA works the best which leads to the highest network throughput, followed by the performance of JRRA-PC and JRRA-SP, respectively. This is because JRRA selects route with maximal possible residual capacity at each hop, thus the packets are dispersed widely and concurrent transmission can be fully utilized.

Received Video Data Quality: Figures 14(a) to (d) present the effect of different node degree values on the streaming data quality coming from the accepted HP cameras. The data quality is classified based on the allocated DR as in Fig. 11. From the figures, we can see that the percentage of HP nodes accepted at better quality, increases with the increased node degree in the optimal solution. This is because more possible routes are available in the network with possibly better capacity, and the optimal solution provided by the MILP is able to select the path with best capacity and thus the HP cameras are allocated a better rates. The shortest-path routing does not take into consideration link capacity when constructing RT as a result a path with low end-to-end capacity may be selected. That is why JRRA-SP performance remains the same and does not take advantage of the available better capacity paths.

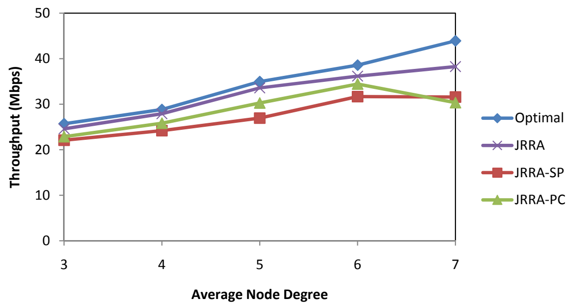
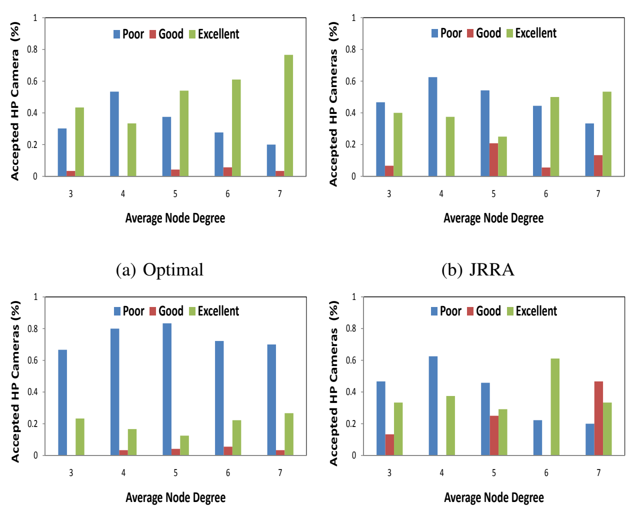


Figure 13. Network throughput vs. average node degree (number of neighbors).



(a) Optimal (b) JRRA

(c) JRRA-SP (d) JRRA-PC

Figure 14. Received video quality of accepted HP nodes vs. average node degree (number of neighbors).

6. Conclusions

This work addresses guaranteed transmission of video flows problem in WiMAX mesh networks for surveillance systems. In such traditional surveillance systems, video quality must be kept above a certain threshold to be able to perceive the contents. When system throughput drops, nodes (cameras) data rates drop equally and the utility of the whole system drops drastically. In crucial situations where available throughput is insufficient to satisfy the streaming video data from all the cameras, we proposed a novel cross-layer scheme that decides which camera(s) to put offline so that overall utility of, especially the HP cameras, whole video surveillance system improves. We have proposed a novel Joint Routing and Rate Assignment protocol, termed JRRA, to maximize the throughput of WiMAX surveillance system with QoS guarantee. We also formulated the problem as an optimization problem i.e., Mixed Integer Linear Program (MILP) and provided solution to it. Simulation results validated the performance of the proposed solution and proved its effectiveness.

References

[1] S. Manap, K. Dimyati, M. N. Hindia, M. S. Abu Talip, and R. Tafazolli, "Survey of radio resource management in 5g heterogeneous networks," *IEEE Access*, vol. 8, pp. 131 202–131 223, 2020.

[2] I. Sousa, M. P. Queluz, and A. Rodrigues, "A survey on qoe-oriented wireless resources scheduling," *Journal of Network and Computer Applications*, vol. 158, p. 102594, 2020. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1084804520300680

[3] A. A. Barakabitze, N. Barman, A. Ahmad, S. Zadtootaghaj, L. Sun, M. G. Martini, and L. Atzori, "Qoe management of multimedia streaming services in future networks: A tutorial and survey," *IEEE Communications Surveys Tutorials*, vol. 22, no. 1, pp. 526–565, 2020.

[4] *IEEE Standard for Local and Metropolitan Area Networks; Part 16: Air Interface for Fixed Broadband Wireless Access Systems, IEEE Standard 802.16-2004, IEEE 802.16 Working Group*, IEEE Std 802.16-2004 (Revision of IEEE Std 802.16-2001) Std., 2004.

[5] I. Ahmad and D. Habibi, "High utility video surveillance system on public transport using wimax technology," in *Proc. of IEEE Wireless Communications and Networking Conference (WCNC)*, 2010.

[6] B. Aoun, R. Boutaba, and G. W. Kenward, "Gateway placement optimization in wireless mesh networks with qos constraints," *IEEE JSAC*, vol. 24, pp. 2127–2136, 2006.

[7] N. Ababneh and J. Rougier, "Optimal rate assignment for higher utility wimax surveillance systems," in *Proc. of IEEE Wireless Communications and Networking Conference (WCNC)*, 2012, pp. 2113–2118.

[8] Y. Yang and J. Wang, "Design guidelines for routing metrics in multihop wireless networks," in *in Proc. of IEEE INFOCOM*, 2008.

[9] A. Raniwala and T. cker Chiueh, "Architecture and algorithms for an ieee 802.11-based multi-channel wireless mesh network," in *Proc. of IEEE INFOCOM*, 2005.

[10] D. H. B. Awerbuch and H. Rubens, "High throughput route selection in multi-rate ad hoc wireless networks," Technical Report, Johns Hopkins University, Tech. Rep., 2003.

[11] A. Woo, T. Tong, and D. Culler, "Taming the underlying challenges of reliable multihop routing in sensor networks," in *Proceedings of the 1st international conference on Embedded networked sensor systems*, ser. SenSys '03. New York, NY, USA: ACM, 2003, pp. 14–27.

[12] D. S. J. De Couto, D. Aguayo, B. A. Chambers, and R. Morris, "Performance of multihop wireless networks: Shortest path is not enough," in *Proceedings of the First Workshop on Hot Topics in Networks (HotNets-I)*. Princeton, New Jersey: ACM SIGCOMM, October 2002.

[13] L. Betancur, R. C. Hincapié, and R. Bustamante, "Wimax channel: Phy model in network simulator 2," in *In Proc. of workshop on ns-2: the IP network simulator*, ser. WNS2 '06. New York, NY, USA: ACM, 2006.

[14] D. D. Couto, D. Aguayo, J. Bicket, and R. Morris, "A high throughput path metric for multi-hop wireless routing," in *in Proc. of ACM MobiCom*, 2003.

[15] R. Draves, J. Padhye, and B. Zill, "Routing in multi-radio, multi-hop wireless mesh networks," in *in Proc. of ACM MobiCom*, ser. MobiCom '04. New York, NY, USA: ACM, 2004, pp. 114–128.

[16] H.-Y. Wei, S. Ganguly, R. Izmailov, and Z. J. Haas, "Interference-aware ieee 802.16 wimax mesh networks," in *61st IEEE VTC'2005 Spring Vehicular Technology*, vol. 5, 2005, pp. 3102–3106.

[17] L. Skorin-Kapov, M. Varela, T. Hoßfeld, and K.-T. Chen, "A

survey of emerging concepts and challenges for qoe management of multimedia services," *ACM Transactions on Multimedia Computing, Communications, and Applications.*, vol. 14, no. 2s, May 2018. [Online]. Available: https://doi.org/10.1145/3176648

[18] S. Geetha and R. Jayaparvathy, "Dynamic bandwidth allocation for multiple traffic classes in ieee 802.16e wimax networks: A petrinet approach," *Journal of Computer Science*, vol. 7, pp. 1717–1723, 2011.

[19] H. Juan, H. Huang, C. Huang, and T. Chiang, "Scalable video streaming over mobile wimax," in *Proc. of ISCAS*, 2007.

[20] N. Ababneh and J. Rougier, "High utility guarantee video surveillance system using ieee 802.16 wimax networks," in *Proc. of IFIP Wireless Days*, 2012, pp. 1–6.

[21] N. Ababneh and S. Selvadurai, "Topology control algorithms for wireless sensor networks: an overview," *International Journal on Wireless & Optical Communications*, vol. 3, no. 01, pp. 49–68, 2005.

[22] N. Ababneh, "Performance evaluation of a topology control algorithm for wireless sensor networks," *International Journal of Distributed Sensor Networks*, vol. 6, no. 1, 2010.

Nedal Ababneh is the head of Information Security Engineering Technology (ISET) department at Abu Dhabi Polytechnic. He received his PhD in 2009 from The University of Sydney, Australia and Master Degree in 2004 from The University of New South Wales, Australia, both in Computer Science and Engineering. From 2017 to 2019 he served as Senior Lecturer and Program Chair of Undergraduate Program of IT (Networks Engineering, and Web and Mobile Applications Development) at Victoria University, Australia. His main research interests include Internet of Things, Wireless Sensor Networks, Blockchain, Network and Information Security, and Steganography. Dr. Ababneh has published a number of journal and conference papers in top international venues. Dr. Ababneh is a member of IEEE, IEEE Communication Society (ComSoc), and Australian Computer Society (ACS).