

Research Article

Optimal Cross-Layer Routing in 802.16 Mesh Networks With Different Classes of Service

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Abstract: Permanent interest in wireless mesh networks can be explained by their fast and easy deployment, self-configuring, self-healing, and large covered area. Substantially the advantages are related to possibility of every mesh-station to work as end-terminal and as transit node at same time. In turn the capability gives rise to set of problems one from which is routing. In order to improve network efficiency and in compliance with next generation network's concept routing must be optimal, adaptive, QoS-based and take into account underlying link layer. Whereas IEEE 802.16 mesh networks are based on TDMA/OFDM the routing problem must be solved jointly with slot allocation. The article offers dynamic mathematical model of IEEE 802.16 mesh network in space of state that allows to formulate cross-layer routing as constrained optimization problem taking into account requirements to bandwidth and delay of traffic delivery. Model is aimed at slot reuse and multipath forwarding. As a result it allow to improve network productivity up on 30-100% legacy single path delivering.

Keywords: cross-layer optimization, quality of service, routing, slot allocation, WiMax, wireless mesh network.

INTRODUCTION

Main gains of Wireless Mesh Networks (WMNs) in comparison with conventional point-to-multipoint cellular-like networks are related to capacity and reliability improving and widening of covered area. It's caused by higher network connectivity so long as every mesh-station can work as client and as router for other clients at same time, uplink and downlink aren't separated and traffic flow can be transmitted through any available interface. Technologically WMNs can be built by using IEEE 802.11, 802.15 or 802.16 standards. Last one describes WiMax (Worldwide Interoperability for Microwave Access) wireless networks which were developed to provide high bandwidth access to large number of users [1]. In the article we'll focus on the WiMax mesh networks.

DEFINITION OF CROSS-LAYER ROUTING PROBLEM IN 802.16 MESH NETWORKS

Like as every next generation telecommunication network IEEE 802.16 WMN must satisfy to set of requirements. On one hand it's providing of wide range of applications with different levels of Quality of Service (QoS) and growing amount of user's traffic. On the other hand it's scalability, robustness, easy in maintenance and low cost that gives rise to problem of network performance improving. In turn, it toughens up the requirements for traffic control problem which includes two fundamental subproblems, QoS-routing and link resource allocation. QoS-routing corresponds to finding the best path (or paths) from source to destination along which amount of available resources allows delivering of serviced flow with required QoS parameters. Next step is related to assignment required amount of link resources to the flow. Solving of the problems significantly depends on type (nature) of controlled resources. Workgroup IEEE 802.16 defines Time-Division Multiple Access (TDMA) together with Orthogonal Frequency Division Multiplexing (OFDM) as main mode of WiMax WMN [1]. Then as single unit of link resources is defined time slot (so called minislot) which joins several OFDM-symbols and carries some portion of data. In turn, amount bytes carried by single OFDM-symbol and as a result by single slot depend on type of modulation and coding scheme choice of which is determined by current signal to noise ratio on the link. Thus, problem of the link resources allocation rises to the problem of time slot assignment.

There are some factors that must be taken into account when solving of routing and slot allocation problems in WiMax WMN. Most significant factor which affects almost all processes in wireless networks is interference from transmission of neighboring stations. If some slot or set of slots is used by some wireless station there is no neighbors that can use the slot or the set of slots. Taking into account effect of hidden station reuse of slot (slots) becomes to be possible if and only if distance between the competitive stations is more than 2λ [2]. In whole the interference condition limits capacity of wireless network and affects slot allocation process.

The next important factor is related to QoS requirements which must be ensured when delivering user's traffic. The requirements are preset boundary values for end-to-end delay, packet loss and data rate that define amount of resources (number of slots) should be allocated in every link along used path. So far as current amount of available resources depends on set of slots used by 2-hops neighbors choosing of route must be based not only on QoS requirements and amount of unused slots but takes into account the interference effect. As a result the considering interference condition leads to higher quality and network productivity in whole. In addition in order to improve network reliability and achieved quality of service routing in WiMax WMN must be multipath. As we'll show below multipath routing in wireless environment allows saving link resources by reusing of slots in disjoint paths.

Thus routing and resource allocation problems are closely associated and interpenetrating. From the viewpoint their joint design becomes preferable. Though that all described in literature approaches can be divided into two groups, based on joint or separate solution. The separation can be explained by simplification where routing problem is related to finding best route as sequence of links and nodes from source to destination but allocation problem is associated with assignment some set of slots in links along given route. The process is iterative, shortage of slots in at least one link doesn't allow satisfying QoS requirements and gives rise to route recalculation. An advantage of the approach is related to possibility to use for path finding any from developed for ad-hoc networks routing protocols, distance vector (for example AODV, DSDV) or link state (for example OLSR), almost all of which can be implemented in WiMax WMN [3, 4]. In order to improve quality of routing there are proposed to search path with taking into account state of wireless connections at physical and link layers by using composite (cross-layer) metrics. For example in [5] cost route metric combines end-to-end delay in the route, power and link quality estimated via Exclusive Expected Transmission Time (EETT). Work [6] assumes multi-channel interfaces of WiMax mesh-stations and for the case proposes Multiple Channel One Pass (MCOP) metric that reflects physical parameters such as modulation and coding scheme and number of channels. Works [3, 7] give sufficiently complete classification of different cross-layer routing metrics for WMNs. In whole although the metrics attempt to take into account different parameter and even interference effect the process of path finding is based on shortest path algorithms.

Within separate approach next after routing step is related to slot allocation. Often for the purpose distance-2 graph coloring is used [8, 9]. The algorithm ensures that all nodes within same collision group will have different colors (to eliminate interference effect) and allows such slot allocation that total number of slot (colors) should be optimized. Work [6] proposes other heuristic algorithm main idea of which is replacement initial multihop route by single hop by using pre-calculated maximal end-to-end rate (MEER) for every station. The MEERs allow allocating available set of slots among stations fairly.

Thus the partitioning of routing and slot allocation problems where every from them is solved mainly by heuristic algorithms doesn't allow maximizing slot utility and network productivity in whole. On other hand as a rule proposed in literature algorithm for joint routing and slot allocation are based on heuristics too. For example work [10] offers to send set of probe packets along all pre-established disjoint paths from source to destination. Based on feedback report which will contain residual energy, bandwidth, and delay for every path source selects best robust path suitable to QoS requirements. Idea of probes or path request messages lies in the basis of works [11, 12].

Thus analysis of literature allows formulating set of requirements to which perspective methods of traffic control, including routing and link resource allocation, in WiMax WMN must meet. In order to achieve maximum productivity of wireless mesh network:

1. Routing and slot allocation problems must be solved jointly.
2. The integrated problem of cross-layer routing must be formulated as optimization problem that requires appropriate mathematical model of WiMax WMN.
3. The mathematical model must be flow-based and taking into account QoS-requirements, be aimed at multipath forwarding, be dynamic and taking into account current state of WMN's links and nodes and interference between them.

In compliance with the requirements the article offers appropriate mathematical model of WiMax WMN.

MATHEMATICAL MODEL FOR OPTIMAL CROSS-LAYER ROUTING IN 802.16 MESHNETWORK

Satisfaction to part of before defined requirements can be achieved by using set of differential equalities to develop mathematical model of WiMax WMN in space of states [13]:

$$q_{i,j}^z(k+1) = q_{i,j}^z(k) - \sum_{\substack{v \in S_i^1 \\ v \neq i}} \sum_{r=1}^{N_F} m_{i,v}(k) \tau_{i,v}^{r,j,z}(k) n + \sum_{\substack{g \in S_i^1 \\ g \neq i,j}} \sum_{r=1}^{N_F} m_{g,i}(k) \tau_{g,i}^{r,j,z}(k) n + \xi_{i,j}^z(k) \Delta t, \quad (1)$$

$$(i, j) \in E, i, j = \overline{1, N_v}, j \neq i, z = \overline{1, N_{QoS}},$$

where $k = 0, 1, 2, \dots$; $\Delta t = t_{k+1} - t_k$ is the sampling interval (period of re-computation and change of control variables); $\tau_{i,v}^{r,j,z}(k)$ is binary control variable, defined as

$$\tau_{i,j}^{r,l,z} = \begin{cases} 1, & \text{if } r\text{-th slot is used in the link } (i, j) \\ & \text{for transmission of the flow addressed to } l\text{-th station,} \\ & \text{in the frameworks of } z\text{-th class of service;} \\ 0, & \text{otherwise,} \end{cases}$$

$q_{i,j}^z(k)$ is state variable representing the data volume within z -th class of service (CoS) that is kept at the instant t_k in buffer of the i -th station and intended for transmission to the j -th station; $m_{i,j}$ is number of bits of the user's data that can be carried by one slot in link $(i, j) \in E$; E is a set of links between stations of a mesh-network; S_i^1 is a set of distance-1 neighboring stations to the i -th station; $\xi_{i,j}^z(k)$ is the intensity of the data arrival to the i -th station at the instant of time t_k in the frameworks of the z -th class of service addressed to the j -th station; n is the number of the frames transmitted during time Δt , $n = \Delta t / T_F$; T_F is the frame duration; N_F is an number of slots per frame which is used for transmission of a user's traffic; N_v is a total number of stations in mesh-network; N_{QoS} is an number of QoS-classes supported by the network.

In compliance with physical meaning of defined variables and limited amount of network resources following inequalities must be bringing into mathematical model. If to assume that the packets of different QoS-classes are serviced in different queues, condition of limited buffer size can be written as

$$q_{i,j}^z(k) \geq 0, \quad \sum_{\substack{j=1, \\ i \neq j}}^{N_v} q_{i,j}^z(k) \leq q_i^{z \max}, \quad (2)$$

or, in case of common (aggregated) queue it becomes

$$\sum_{z=1}^{N_{QoS}} \sum_{\substack{j=1, \\ i \neq j}}^{N_v} q_{i,j}^z(k) \leq q_i^{\max}, \quad (3)$$

where $q_i^{z \max}$ is the maximal size of the queue assigned to the z -th CoS at the i -th mesh station; q_i^{\max} is total size of buffer at i -th mesh station.

The control variables $\tau_{i,v}^{r,j,z}(k)$ correspond to slot allocation process where interference plays key role. There are two approaches to eliminate interference effect; first one is one-time utilization of every slot that can be represented as

$$\sum_{z=1}^{N_{QoS}} \sum_{\substack{(i,j) \in E, \\ j \neq i}} \sum_{\substack{l=1, \\ l \neq i}}^{N_v} \tau_{i,j}^{r,l,z}(k) \leq 1 \text{ for every } i = \overline{1, N_v}. \quad (4)$$

However, in order to improve capacity of WMN reuse of the slots must be approved. Then condition (4) is complicated and becomes

$$\sum_{z=1}^{N_{QoS}} \sum_{\substack{(i,j) \in E, \\ j \neq i}} \sum_{\substack{l=1, \\ l \neq i}}^{N_v} \tau_{i,j}^{r,l,z}(k) + \sum_{z=1}^{N_{QoS}} \sum_{\substack{(g,j) \in E, \\ g \in S_i^2, \\ g \neq j}} \sum_{\substack{l=1, \\ l \neq i}}^{N_v} \tau_{g,j}^{r,l,z}(k) \leq 1 \text{ for every } i = \overline{1, N_v}, \quad (5)$$

where S_i^2 is a set of stations interfered to the i -th station.

Within next generation networks all tasks must be solve from viewpoint of Quality of Service that means traffic delivery with ensuring its set of QoS requirements to end-to-end rate, delay, jitter and packet loss. In wireless networks packet losses can be caused by two reasons, poor signal to noise ratio in links and overflow of buffers in the nodes (stations). In first case deterioration of signal to noise ratio leads to change type of modulation type and coding scheme that in turn results in lower data rate in the link. The overflow of buffer within proposed model is intercepted by conditions (2) and (3). Taking into account that as a rule jitter is decreasing together with decreasing of delay QoS requirements on network layer can be reduced to

$$\begin{cases} B_{\Sigma}^z \geq B_{req}^z, \\ D_{\Sigma}^z \leq D_{req}^z, \end{cases} \quad (6)$$

where B_{Σ}^z and D_{Σ}^z are achieved total end-to-end rate and delay respectively within z -th class of service; B_{req}^z and D_{req}^z are required end-to-end rate and delay within z -th class of service.

By using before defined variables rate requirements can be written as

$$\sum_{r=1}^{N_F} m_{i,j}(k) \tau_{i,j}^{r,l,z} \geq B_{req}^z \quad (7)$$

or

$$B_{req}^z \min \leq \sum_{r=1}^{N_F} m_{i,j}(k) \tau_{i,j}^{r,l,z} \leq B_{req}^z \max, \quad (8)$$

where B_{req}^z is the transmission rate of flow required by the user; $B_{req}^z \max$ and $B_{req}^z \min$ are maximum and minimum values of the transmission rate of flow guaranteed by the network.

Total end-to-end delay of delivering in WiMax WMN is given by [8, 13] (to simplify notation index of class of service was omitted)

$$D_{\Sigma} = 0.5 \cdot T_F + D_q + D_{s-d} + 2T_s, \quad (9)$$

where D_q is primary (conventional) queuing delay; D_{s-d} is delay equal to time interval between the first slot and the slot allocated to carry given packet for station-destination; T_s is slot duration.

Assuming that outgoing interface of wireless mesh station can be described as queuing system with constant servicing time T_F , i.e. $M/D/1$ system, primary queuing delay D_q can be calculated as [8]

$$D_q = \frac{\rho}{2(1-\rho)} T_F, \quad (10)$$

where $\rho = \lambda T_F$, λ is intensity of packet arriving, 1/s.

Proposed mathematical model of WiMax WMN (1) – (10) projects the user's requests onto slot allocation via control variables $\tau_{i,v}^{r,j,z}(k)$ which must be found with meeting buffer constraints (2) – (3), interference constraints (5) and QoS-constraints (6) – (10). Choosing of appropriate objective function is risen from following reasons. Firstly, objective function must be aimed at saving of link and buffer resources, it does cost function as most preferable form. Because reuse of slots furthers resource saving objective function must stimulate the reusing. Additionally as it is shown in works [8, 13] order of slot assigned along delivering path from source to destination affects total end-to-end delay, then objective function must supervise the order. Then objective function for optimal joint routing and slot allocation can

be formalized as

$$J = \sum_{k=1}^a [\bar{q}^T(k)W_q\bar{q}(k) + \bar{\tau}^T(k)W_\tau\bar{\tau}(k) - \bar{\tau}^T(k)W_{reuse}\bar{\tau}(k) + \bar{\tau}^T(k)W_{seq}\bar{\tau}(k)] \rightarrow \min, \tag{11}$$

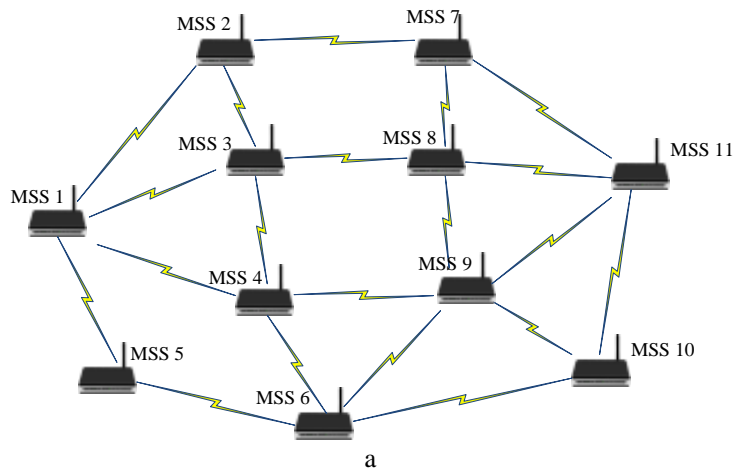
where a is the number of intervals Δt , for which the control variables should be calculated; $\bar{q}(k)$ is vector of state variables $q_{i,j}^z(k)$ at the instant of time t_k ; $\bar{\tau}(k)$ is vector of control variables $\tau_{i,v}^{r,j,z}(k)$; W_q, W_τ are the diagonal weight matrices of buffer and link resources usage respectively, W_{reuse} is the weight matrix presenting a gain at the cost of the slots reuse; W_{seq} is the weight matrix presenting a breach of the order of slots along the path. Its element is 0 if sequence number of slot in a link is higher than sequence number of slot used in previous link and more the 0 if sequence of slots is broken.

Thus the mathematical model of WiMax WMN (1) – (11) allows to find optimal solution for cross-layer QoS-routing with taking into account dynamics of flows and state of WMN’s links and nodes, and interference between them.

PERFORMANCE ANALYSIS

In order to evaluate the performance of proposed model (1)–(11) a simulation was conducted. In the simulation for different wireless mesh networks we solved cross-layer routing as optimization problem (11) subject to (1)–(2), (5)–(7), (9)–(10). Simulated network structures are shown in fig. 1. We assumed all stations are mesh subscriber stations (MSS) every from which can work as source, destination and transit router. All links are assumed to have same quality and transmission rate. Chosen link parameters are following: frame duration $T_F=20$ ms, slot duration $T_s=12.5$ μ s, type of modulation is 16QAM, coding rate is $\frac{3}{4}$. It means one frame contains 1600 OFDM-symbols which must be allocated among 256 user’s data slots and control slots. Assumed 5 control slots (MSH_CRTL_LEN=5) every from which has 7 OFDM-symbols we have 6 OFDM-symbols per user’s data slot. Chosen modulation type and coding scheme defines 72 bytes of data per OFDM-symbol. Then one frame with length 20 ms can carry in every slot 432 bytes of data. It corresponds to data rate 172.8 kbps when one slot is using in every frame.

To simplify the simulation process we assumed two classes of service: low-cost “bronze” class and high-quality “gold” class. “Gold” class includes all requests sensitive to end-to-end delay such as voice and video calls. It means that control decision for request within “gold” CoS must meet to both of QoS-constraints from (6). Traffic within “bronze” class is tolerant to delay and it must be serviced according to required rate B_{req}^{bronze} . Under high load and shortage of network resources it’s allowed to deliver traffic of “bronze” class with lower than required rate.



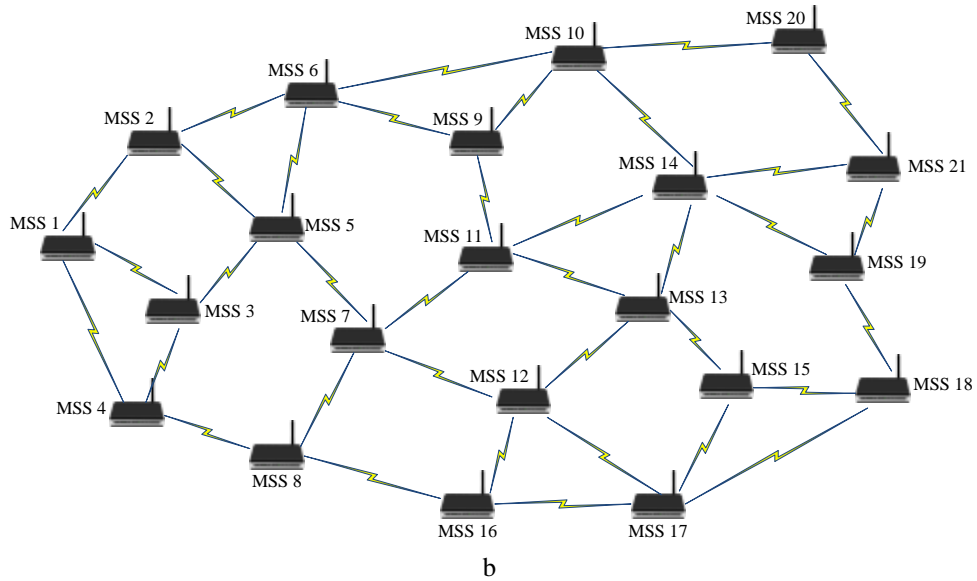


Fig-1: Simulated wireless mesh networks

Examples of different routing and slot allocation solutions for network #1 (fig. 1, a) are given in fig. 2 and 3. In both cases traffic was generated by station MSS 7 and addressed to station MSS 6. In first scenario (fig. 2) all traffic belongs to “gold” class with requirements $B_{req}^{gold} = 500$ kbps and $D_{req}^{gold} = 40$ ms. Under chosen link parameters satisfaction of rate requirement is related to finding path (or paths) with total equivalent capacity 3 slots per frame. Resulting optimal cross-layer routing was obtained as solution of problem (11) and it is shown in fig. 2. The solution defines three paths for delivering traffic from MSS 7 to MSS 6:

- path 1 MSS 7 – MSS 2 – MSS 1 – MSS 5 – MSS 6 along which slots with numbers 2, 3, 4 and 6 are assigned;
- path 2 MSS 7 – MSS 11 – MSS 9 – MSS 6 along which slots with numbers 1, 4 and 5 are used;
- path 3 MSS 7 – MSS 11 – MSS 10 – MSS 6 along which slots 6, 7 and 8 are assigned.

The slot allocation defines some delay in every path. Figure 2 shows delivering delays from source to destination D'_{s-d} which takes into account transmission time in both the source and destination MSSs, i.e. $D'_{s-d} = D_{s-d} + 2T_s$. In compliance with (9) end-to-end delivery delay along path 1 is 10.57 ms, along path 2 is 10.49 ms, along path 3 is 10.72 ms. So total multipath end-to-end delay is maximum delay among all used paths and it equals to 10.72 ms.

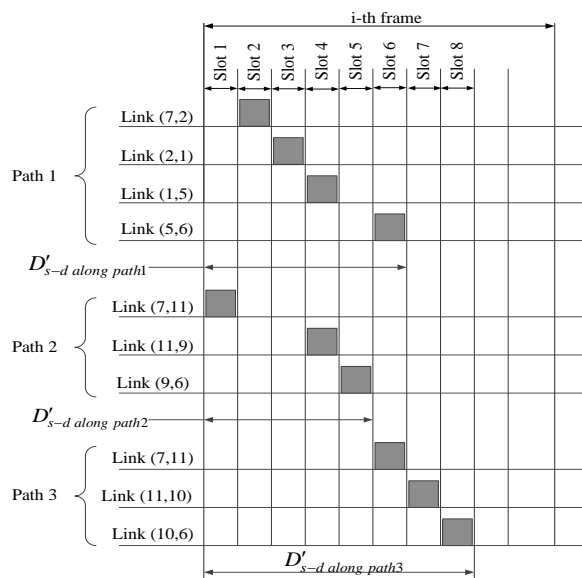


Fig-2: Example of cross-layer routing for “gold” class of service

Thus servicing of “gold” traffic required 8 slots and moreover minimal delay was achieved. Now let us define amount of traffic in “bronze” class that can be delivered between same pair of MSSs by using same number of slots. Appropriate solution is shown in fig. 3. It defines above mentioned three paths with total equivalent capacity 4 slots per frame that rises to resulting rate $4 \times 172.8 = 691.2$ kbps. In compliance with (9) end-to-end delivery delay along path 1 is 50.49 ms, along path 2 is 30.41 ms, along path 3 is 30.27 ms. So total multipath end-to-end delay in comparison with first scenario is growing from 10.72 to 50.49 ms. Thus relaxation of delay requirement and corresponding absence of component $\bar{\tau}^T(k)W_{seq}\bar{\tau}(k)$ in objective function (11) lead to increasing of traffic rate or in other words to saving of link resources by changing of order of slot allocation.

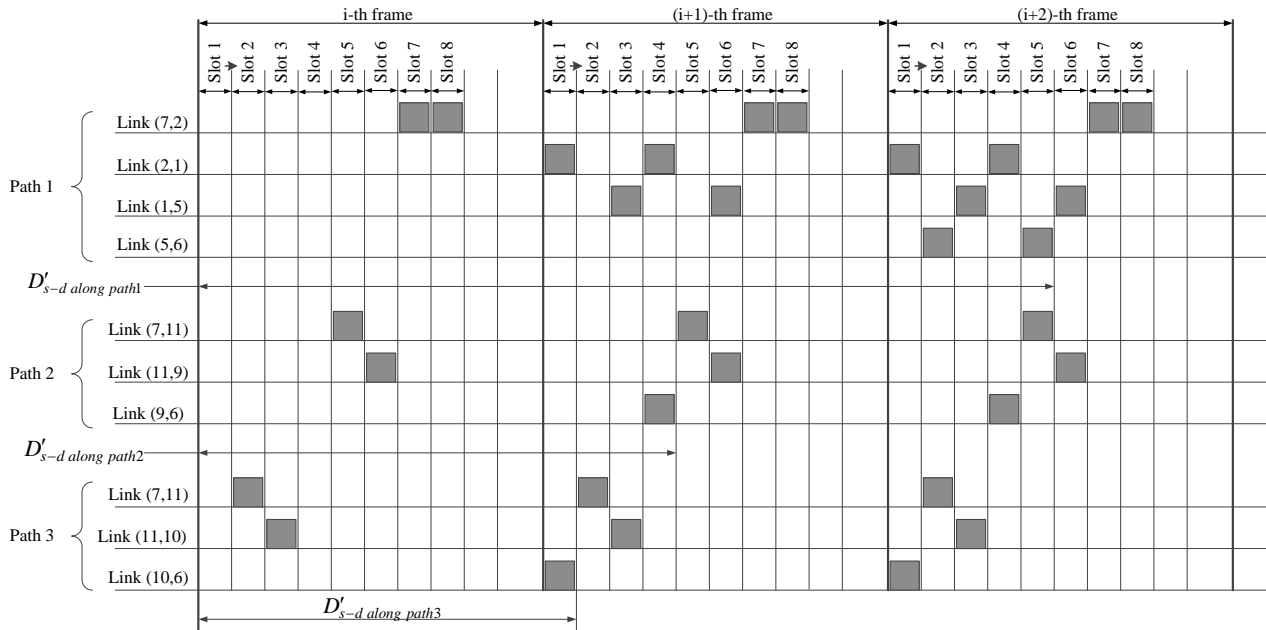


Fig-3: Example of cross-layer routing for “bronze” class of service

Diagrams in fig. 4 show maximum data rates that are possible between pair MSS 7 - MSS 6 in network #1 (fig. 1, a) within different classes of service. Here “gold” class is divided into two subclasses: traffic that is delivered within 1 frame, in the case all slots are assigned along paths sequentially and as a result $D'_{s-d} < T_F$, and traffic for which end-to-end delay includes at least 1 whole frame, i.e. $D'_{s-d} > T_F$. As far as for “bronze” class delay requirement is relaxed in the case achieved maximum data rate is 48.8% higher than maximum low within “gold” class. At same time difference in delays reaches up to 2 – 3 times.

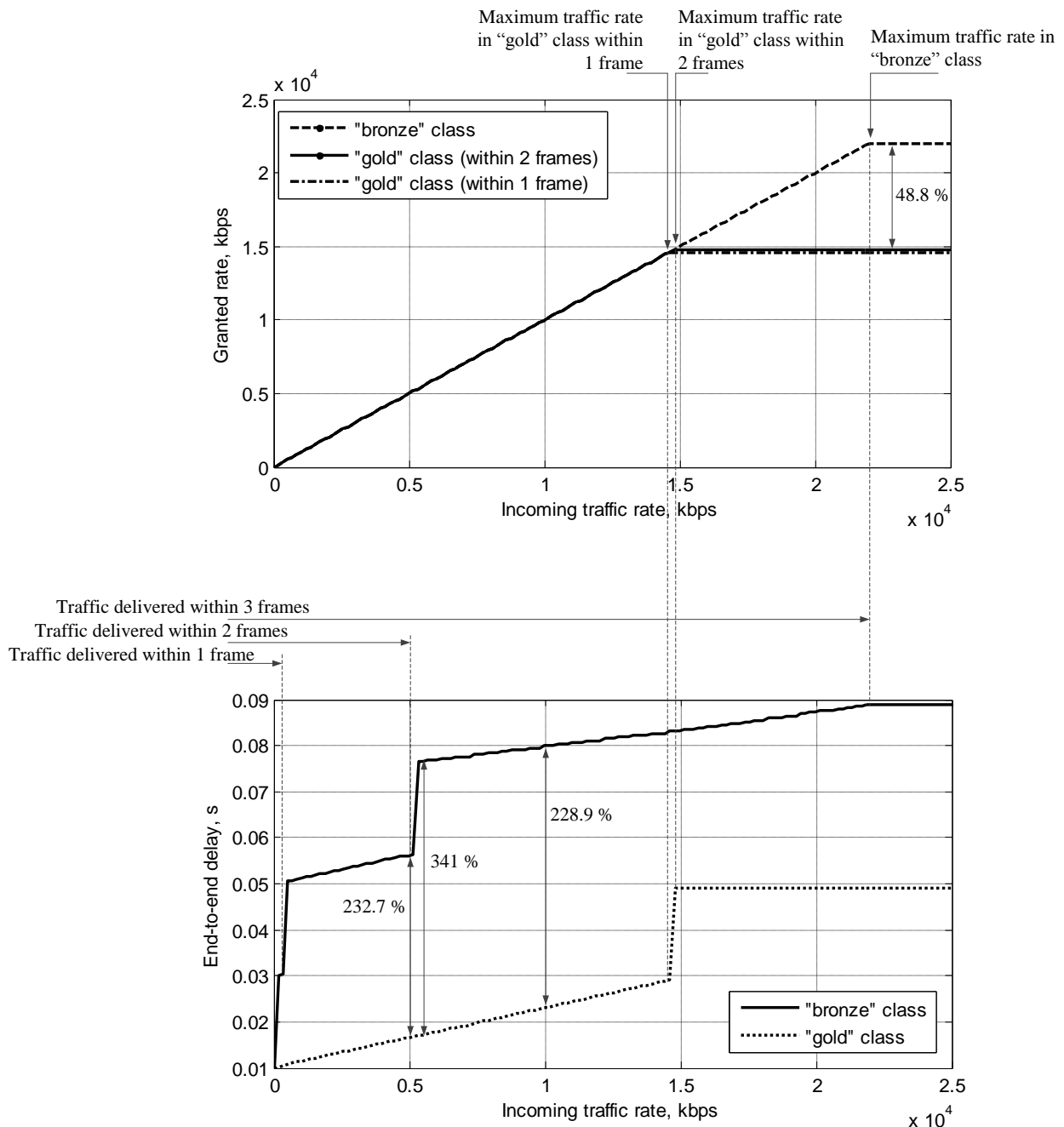


Fig-4: Dependence of resulting granted rate and achieved end-to-end delay on rate of traffic arriving

Thus dependence of granted rate (in other words productivity of network) on incoming traffic for “bronze” class defines upper bound for flow between given pair of stations but similar dependence for “gold” class defines upper bound for flow with highest quality of service. By averaging of the dependences for all pairs across network average network productivity can be estimated. The characteristic plays important role for dynamic call admission control to accept or deny new request.

In whole maximum flow between given pair of stations depends on distance between them. It’s related to different number of slots required to deliver same traffic along different number of links. For example for directly connected stations (1 hop distance in fig. 5) all vacant slots can be used. If to assume all 256 slots are vacant then maximum rate between the stations becomes $256 \times r_s$ where r_s is data rate achieved by using one slot in every frame along chosen path. As it was noted above under 16QAM (3/4) $r_s = 172.8$ kbps, so for directly interacting stations maximum flow is bounded by $256 \times 172.8 = 44237$ kbps. If distance between source and destination becomes 2 hops the initial number of slots must be allocated between two link (fig. 5). As a result maximum flow is reduced to 2 times.

For stations distance between which is 3 hops and more maximum flow can be estimated as $\frac{256 \times r_s}{3}$ if all 256 slots are vacant.

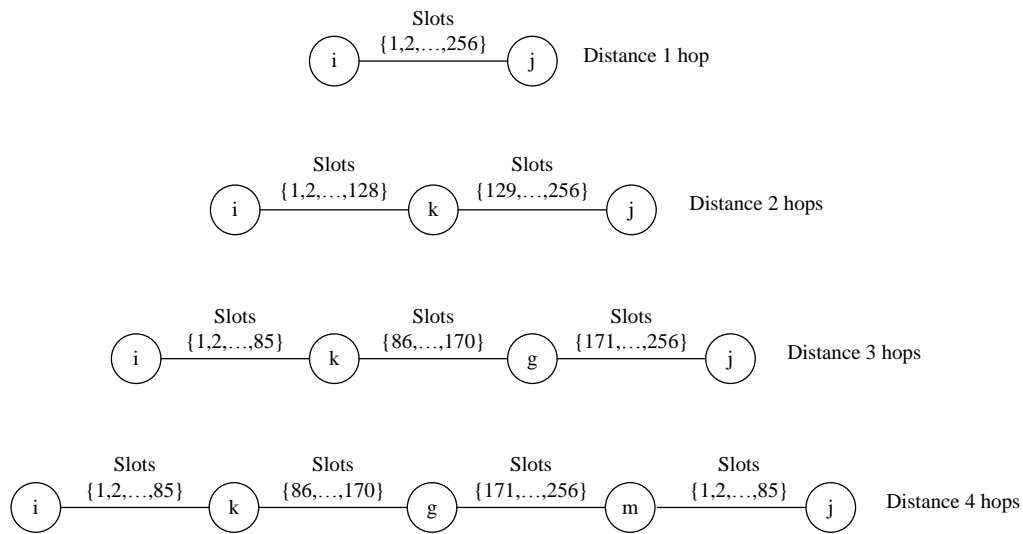


Fig-5: Examples of slot allocation between stations at different distances

Simulation results for different pairs of MSSs within different structures (fig. 1) are given in table 1 and fig. 6.

The results demonstrate that thanks to multipath traffic delivering maximum flow is bounded by $\frac{256 \times r_s}{3}$ for “gold” class and by $\frac{256 \times r_s}{2}$ for “bronze” class of service.

Table-1:Simulation results for different pairs of MSSs

Distance	Pair source-destination	Structure #1			Pair source-destination	Structure #2		
		Maximum rate of flow, kbps				Maximum rate of flow, kbps		
		“bronze” CoS	“gold” CoS within 1 frame	“gold” CoS within 2 frames		“bronze” CoS	“gold” CoS within 1 frame	“gold” CoS within 2 frames
1	1 – 3	44032	44032	44032	1 – 3	44032	44032	44032
2	1 – 6	22016	22016	22016	1 – 5	22016	22016	22016
3	7 – 6	22016	14620	14792	1 – 7	19092	14620	14792
4					1 – 11	21844	14448	14792
5					1 – 13	21844	14448	14792
6					1 – 19	21812	14448	14792

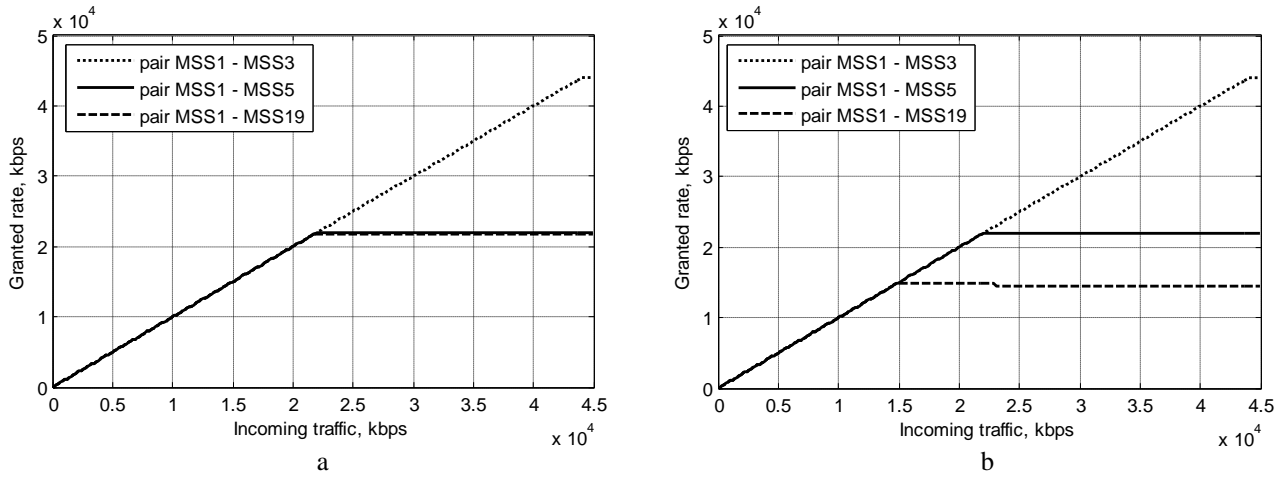


Fig-6: Dependence of resulting granted rate on rate of traffic arriving for different pairs source-destination (a – “bronze” CoS, b – “gold” CoS)

However the boundaries can be reached if and only if source and destination are connected by two or more interference-independence paths where transit stations in different paths don't interfere to each other and slot reuse is possible. For example within structure #1 (fig. 1, a) between MSS 7 and MSS 6 two such paths can be found: MSS 7 – MSS 2 – MSS 1 – MSS 5 – MSS 6 and MSS 7 – MSS 11 - MSS 10 - MSS 6. At same time within structure #2 (fig. 1, b) between MSS 1 and MSS 7 all shortest paths (MSS 1 – MSS 2 – MSS 5 - MSS 7, MSS 1 – MSS 3 – MSS 5 – MSS 7, and MSS 1 – MSS 4 – MSS 8 – MSS 7) interfere to each other. In order to avoid the interference effect longer path is used (MSS 1 – MSS 2 – MSS 6 - MSS 9 – MSS 11 – MSS 7) and as a result delivering rate cannot reach upper boundary $\frac{256 \times r_s}{2}$ (see table 1).

Gain in traffic rate due to multipath in comparison with single path delivering is shown in fig. 7 and 8. The gain for z -th class of service was estimated as

$$G^z = \frac{B_{max\ m.p.}^z - B_{max\ s.p.}^z}{B_{max\ s.p.}^z} 100\%, \quad (12)$$

where $B_{max\ s.p.}^z$ and $B_{max\ m.p.}^z$ are maximum rates achieved under single and multipath routing respectively.

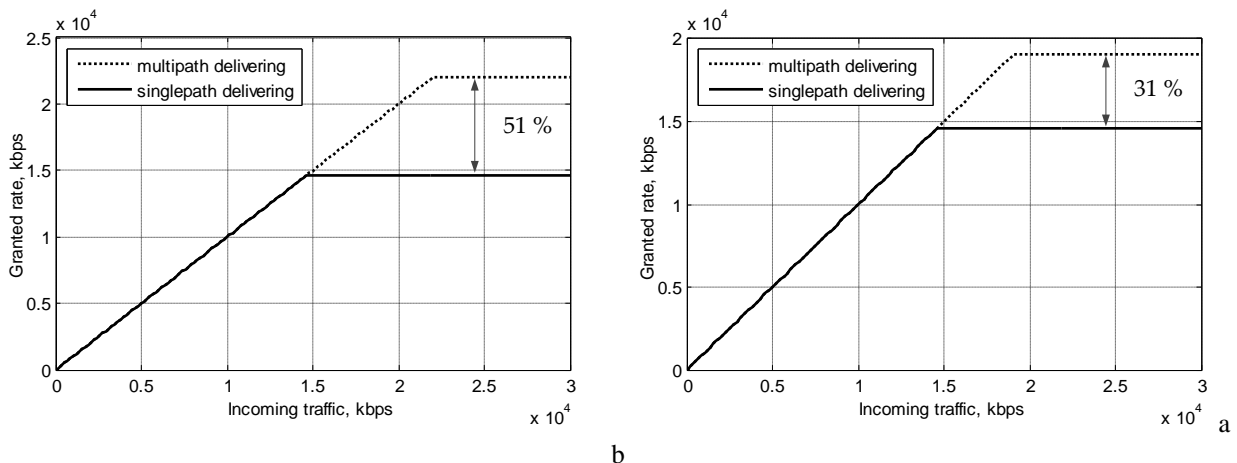


Fig-7: Dependence of resulting granted rate for pair MSS 7 – MSS 6 within structure #1 (a) and pair MSS 1 – MSS 7 within structure #2 (b) under single and multipath

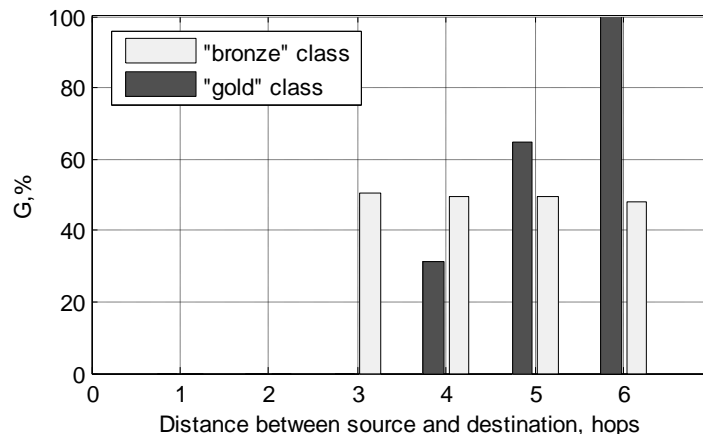


Fig-8: Gain in traffic rate due to multipath in comparison with single path routing

In whole multipath routing in comparison with single path leads to increasing of traffic delivery rates together with delay reducing. Gain due to multipath routing can reach 100% under same amount of available resources and user's QoS-requirements. In other words under same required data rate offered model allows to use lower number of slots due to multipath delivering and slot reusing along the set of paths.

CONCLUSIONS

Offered mathematical model is aimed at optimal cross-layer routing in WiMax (or other TDMA-based) wireless mesh network where different classes of service are supported. As far as the approach doesn't separate routing and slot allocation problem the resulting routes contain enough number of slots that allow ensuring QoS-requirements of user's traffic. In turn the approach facilitates task of call admission control that is very important in general QoS network architecture. The model formulates and solves WMN's routing problem as optimization according to cost objective function which leads to resource saving. Physically it rises to slot reuse and multipath routing. As a simulation results show gain in rate due to slot reuse and multipath routing can reach from 30 up to 100% under same amount of available resources and user's QoS-requirements (delay in the first place). Maximum rate that can be achieved in WMN under offered model approaches network capacity, the rate is affected by number of vacant slots, requested quality level, distance and structure of possible paths between source and destination MSSs.

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