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PERFORMANCE ANALYSIS OF ROUTING IN WIRELESS MESH-NETWORKS BASED ON MODEL IN SPACE OF STATES

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Аналіз ефективності маршрутизації в безпроводових MESH-мережах на основі моделі в просторі станів

Запропонована авторами математична модель безпроводової mesh-мережі з часовим багатостанційним доступом в просторі станів забезпечує оптимальне розв’язання задачі динамічної маршрутизації, яка трактується як задача розподілу канальних ресурсів, тобто слотів. В роботі показано, що модель за рахунок контролю порядку використання слотів здатна забезпечити мінімальну затримку доставки. За рахунок реалізації багатошляхового способу маршрутизації досягається збільшення швидкості передачі трафіка на величину від 20 до 100 % в залежності від типу трафіка та відстані між кінцевими станціями.

Growing popularity of Wireless Mesh Networks (WMN) for delivering voice, video and data in outdoor environments within LAN and MAN can be explained by its possibility to unite capabilities of wired networks together with flexibility of wireless. Modern WMNs provide network capacity, reliability, and security similar to wired networks but at same time they are low-cost, easy and fast deployment. In turn functioning of WMN is related to complicated traffic and resource control in comparison with traditional cellular-like point-to-multipoint wireless networks. Taking into account features of WMN perspective methods of traffic control, including routing and link resource allocation, must meet following requirements. Firstly, traffic control must be based on cross-layer optimization that means joint solution of routing and link resource allocation problems in order to maximize productivity of WMN in whole. Secondary, optimization approach requires appropriate mathematical model of WMN which must be dynamic, flow-based, and QoS-based.

Because there are different ideas of WMN’s realization which are based at different schemes of multiple accesses of mesh-stations to common resource (TDMA, FDMA, or CDMA) in the paper we’ll focus on time-division approach that lies in a basis of WiMax WMN (IEEE 802.16). In work [1] authors proposed a mathematical model of cross-layer optimal routing in TDMA-based WMN with different classes of service (CoS). To control timeslot allocation the model uses binary control variable $\tau_{i,j}^{r,l,z}(k)$ which equals 1 if r-th slot is used in the link (i, j) for transmission of flow addressed to l-th mesh-station (MS) within z-th CoS. State variable $q_{i,j}^{z}(k)$ represents the data volume within z-th CoS that is kept at the instant t_k in buffer of the i-th MS and intended for transmission to the j-th station. Control and state variables are related within following expressions:

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

$$\sum_{z=1}^{N_{QoS}}\sum_{\substack{j=1,\\ i\neq j}}^{N_v} q_{i,j}^{z}(k)\leq q_i^{\max}, \qquad \sum_{z=1}^{N_{QoS}}\sum_{\substack{(i,j)\in E,\\ j\neq i}}\sum_{\substack{l=1,\\ l\neq i}}^{N_v}\tau_{i,j}^{r,l,z}(k)+\sum_{z=1}^{N_{QoS}}\sum_{\substack{(g,j)\in E,\\ g\in S_i^2,\\ g\neq j}}\sum_{\substack{l=1,\\ l\neq i}}^{N_v}\tau_{g,j}^{r,l,z}(k)\leq 1, \quad (2)$$

where $k=0,1,2,\ldots$, $i,j=\overline{1,N_v}$, $j\neq i$, $(i,j)\in E$, $z=\overline{1,N_{QoS}}$, $\Delta t=t_{k+1}-t_k$ is the sampling interval (period of re-computation and change of control variables); $m_{i,j}$ is number of bits of the user's data that can be carried by one slot in link (i,j); 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 MS; $\xi_{i,j}^{z}(k)$ is the intensity of the data arrival to the i-th MS at time t_k in the frameworks of the z-th CoS addressed to the *j*-th MS; *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; N_v is a total number of stations in WMN; N_{QoS} is an number of QoS-classes supported by the network; $q_i^{\max}$ is total size of buffer at i-th MS; S_i^2 is a set of stations interfered to the i-th station.

System of equalities (1) describes dynamic of WMN’s states. Inequalities (2) eliminate overflow of buffers and represent interference effect. In addition assuming the coding and modulation schemes provide sufficient level of packet loss QoS requirements on network layer can be reduced to delay and bandwidth constrains:

$$B_{\Sigma}^{z}\geq B_{req}^{z} \quad \text{and} \quad D_{\Sigma}^{z}\leq D_{req}^{z}, \quad (3)$$

where $B_{\Sigma}^{z}=\sum_{r=1}^{N_F} m_{i,j}(k)\tau_{i,j}^{r,l,z}$ and D_{Σ}^{z} are achieved total end-to-end rate and delay respectively within z-th CoS; B_{req}^{z} and D_{req}^{z} are required end-to-end rate and delay within z-th CoS. Value of D_{Σ}^{z} in WiMax WMN can be calculated according to [1].

Thus optimal joint routing and slot allocation problems within TDMA-based WMN with different CoSs can be formalized as

$$J=\sum_{k=1}^{a}\left[\vec{q}^{\,T}(k)W_q\vec{q}(k)+\vec{\tau}^{\,T}(k)W_{\tau}\,\vec{\tau}(k)-\vec{\tau}^{\,T}(k)W_{reuse}\vec{\tau}(k)+\vec{\tau}^{\,T}(k)W_{seq}\vec{\tau}(k)\right]\rightarrow\min \quad (4)$$

subject to (1) – (3), where a is the number of intervals Δt, for which the control variables should be calculated; $\vec{q}(k)$ and $\vec{\tau}(k)$ are vectors of state and control variables respectively; 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.

According model (1) – (4) a simulation was carried out. Simulation parameters are: T_F =20 ms, slot duration T_s =12.5 µs, type of modulation is 16QAM, coding rate is ¾, MSH_CRTL_LEN=5, that together define data rate 172.8 kbps when one slot is using in every frame. Two classes of service were assumed, low-cost “bronze” class and high-quality “gold” class. Some of obtained results are shown in fig.1.

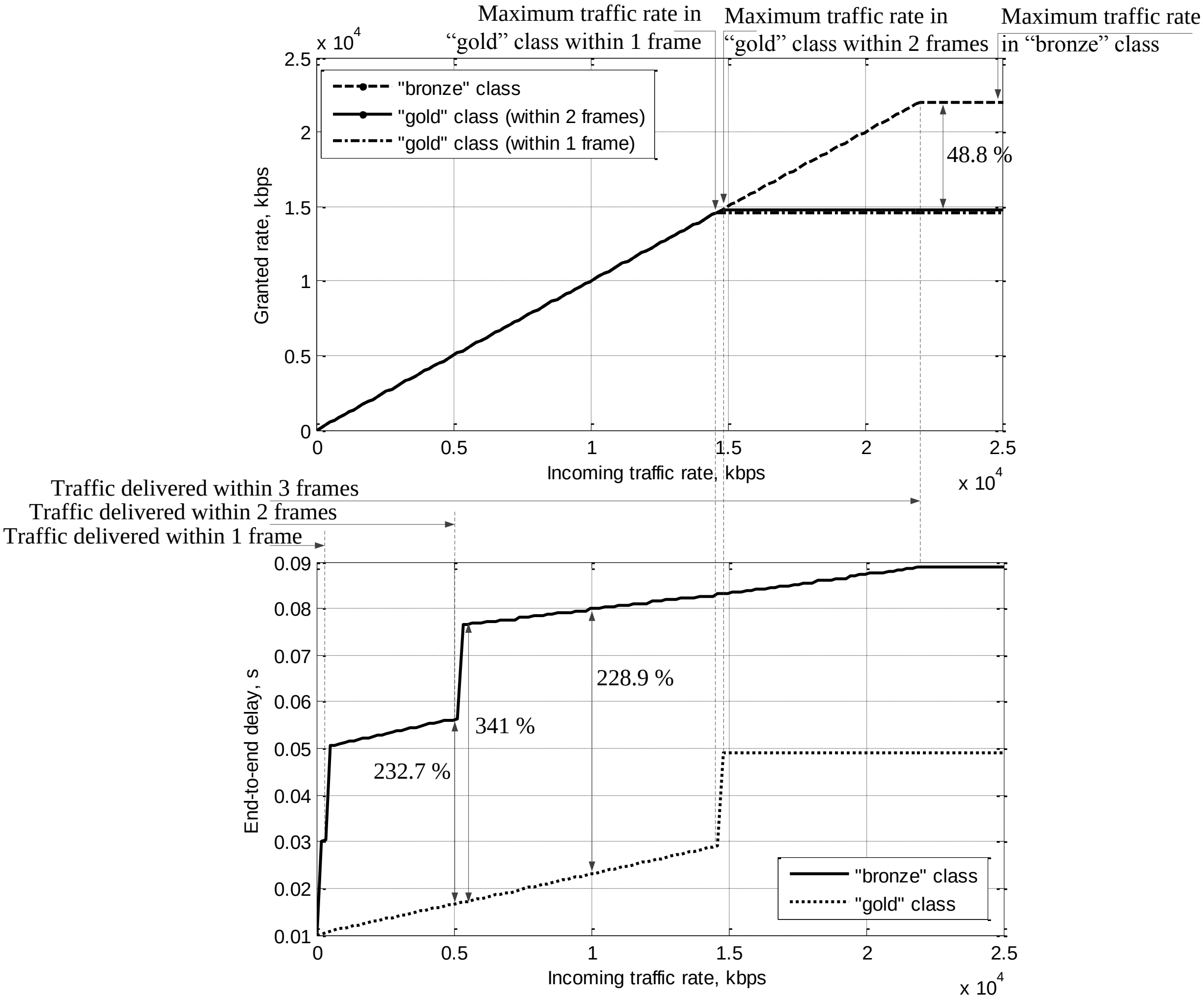

Fig. 1. Resulted quality of service in simulated WMN (number of stations is 11)

As simulation results show the model (1) – (4) allow to deliver traffic within “gold” CoS with minimal delay (2-3 times less than for “bronze” traffic), at same time it reduces maximal rate by 50%. In whole maximum rate between some 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. Proposed model realize multipath routing. In comparison with single path it leads to increasing of traffic delivery rates together with delay reducing. Gain in delivery rate due to multipath routing becomes 40 – 45 % for bronze” traffic and it can reach from 20 up to 100% for 4 to 6-hop distances between source-destination within “gold” CoS under same amount of available link resources.

References

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