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# A Node-Based Time Slot Assignment Algorithm for STDMA Wireless Mesh Networks

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**Short summary:** In this paper authors present a link capacity model for spatial time-division multiple access (STDMA) mesh networks. It makes use of a simplified transmission model that also considers channel fading. The model then forms the basis of a node-based slot-assignment and scheduling algorithm. This algorithm enables the user to exploit multiuser diversity that results in optimizes network throughput. The presented algorithm shows significant improvement in the throughput when compared with existing slot-assignment methods.

## I. Introduction

In STDMA network the transmission time of a channel is divided into slots where multiple slots constitute a frame. These slots are assigned to potential users of the network. The goal of slot assignment scheme is to maximize network throughput. Existing assignment algorithms in STDMA make use of simplified transmission model which do not consider the time-varying fading behavior of a wireless channel. This results in slot wastage when link is in deep fade. The slot is also wasted if scheduled link has no traffic to transmit. This degrades the STDMA network throughput. Therefore a dynamic slot-assignment with that should exploit multiuser diversity is required. However sheer complexity involved in coordinating with all nodes and generating scheduling map in a reasonable time makes this approach impractical. In order to fix these issues the authors present a node-based slot-assignment scheme in which scheduling in each slot is done for nodes not for links. Their contributions include:

- Defining link capacity: a model that includes channel fading. It ensures that whichever link is used by a node will not change the interference profiles on the links selected by other users.
- Node-based time-slot assignment and scheduling algorithms.

## II. System Model

Wireless STDMA mesh network with fixed routers.

Transmissions are organized in frames.

Synchronization among nodes provided through GPS.

Set of nodes are identified and assigned to a slot for their transmission.

Each node maintains a separate queue for each outgoing link and performs scheduling without coordination with other nodes.

Multiprotocol Label Switching (MPLS) multipath routing is used for routing however packets are transmitted in sequence.

Adaptive modulation and time varying fading channels are considered. It is also assumed that wireless channels undergo slow fading. Due to fading channel an instant channel gain will be fed back to transmitter. The duration for feedback is no longer than coherence time (the time for which channel conditions remain same)

Adaptive modulation is implemented that each data packet can be fragmented into multiple segments and each segment can be transmitted in with lowest data rate. If high data rate is available then multiple segments can be transmitted per slot duration.

## III. LINK CAPACITY MODELING

Each node has multiple links and it can exploit multiuser diversity i.e. different links have different traffic and fading conditions. A channel model is presented that includes shadowing and slow fading.

### *A. Signal to interference and noise ratio (SINR) Formulation*

$h_{r,t}$: Channel response function from transmitter ‘t’ and receiver ‘r’

$x_t$: Signal from ‘t’

$I_r, n_I, t_i^{'}$: Set of transmitters causing interference to ‘r’, number of transmitters and i[th] transmitter in $I_r$ respectively. Power control is not considered therefore transmission power of ‘t’ is $pt = E\left(|x_t|^2\right)$. Let $n_0$ be thermal noise with power equal to *k* then received power at ‘r’ is

$$y_{r,t} = h_{r,t}x_t + \sum_{i=1}^{n_I} h_{r,t_i^{'}} x_{t_i^{'}} + n_0 \qquad (1)$$

SINR at receiver ‘r’ is expressed as:

$$\gamma_{r,t} = \frac{|h_{r,t}x_t|^2}{\sum_{i=1}^{n_I} \left|h_{r,t_i^{'}} x_{t_i^{'}}\right|^2 + \kappa} = \frac{|h_{r,t}|^2 p_t}{\sum_{i=1}^{n_I} \left|h_{r,t_i^{'}}\right|^2 p_{t_i^{'}} + \kappa} = \frac{s_0}{\sum_{i=1}^{n_I} s_i + \kappa} \qquad (2)$$

Here $s_0 = |h_{r,t}|^2 p_t \ and \ s_i = \left|h_{r,t_i^{'}}\right|^2 p_{t_i^{'}}$ . The Channel response function consists of three parts:

- Path loss
- Shadowing
- Fading

$$h_{r,t} = \sqrt{l_{r,t}^{-\alpha} 10^{\frac{f_{r,t}}{10}} \pi_{r,t}} \qquad (3)$$

Where $l_{r,t}$ is distance between 't' and 'r', $\alpha \mapsto [2-4]$ (constant), $10^{\frac{f_{r,t}}{10}}$ is shadowing effect and it is modeled as a log-normal distributed random variable. $\pi_{r,t}$ is fading effect and it is defined as complex Gaussian RV with mean and variance equal to 0 and 1 respectively. PDF of $s_0$ and $s_i$ are defined as:

$$p_{s_0}(\alpha_0) = \tfrac{1}{\rho_0} e^{-\frac{\alpha_0}{\rho_0}} \qquad (4a)$$

$$p_{s_i}(\alpha_i) = \tfrac{1}{\rho_i} e^{-\frac{\alpha_i}{\rho_i}} \qquad (4b)$$

Here $\rho_0 = E(s_0) = l_{r,t}^{-\alpha} 10^{\frac{f_{r,t}}{10}} p_t$ and $\rho_i = E(s_i) = l_{r,t_i'}^{-\alpha} 10^{\frac{f_{r,t_i'}}{10}} p_{t_i'}$

*B. PDF of SINR*

**Case 1**: no interference is observed by receiver 'r' i.e. ($I_r$=0, $n_I$=0) then PDF of $\gamma_{r,t}$ , is defined as: let $\delta = {}^{\gamma_0}\!/\!_{\kappa}$

$$p_{\gamma_{r,t}}(z) = p_{s_0}(z\kappa) = \tfrac{1}{\delta} e^{-\frac{z}{\delta}} \qquad (5)$$

Probability that $\gamma_{r,t}$ is smaller than $w$ is defined as:

$$Pr\left(\gamma_{r,t} \geq w\right) = \int_w^\infty p_{\gamma_{r,t}}(z)dz = e^{-\frac{w}{\delta}} \qquad (6)$$

**Case 2:** unit interference is observed by 'r' i.e. ($I_r$>0, $n_I$=1) then PDF of term ($s_i$+k i.e. denominator of equ.2) is defined as:

$$p_{s_1+\kappa}(v) = \tfrac{1}{\sigma_1} e^{-\frac{v-\kappa}{\sigma_1}} \qquad (7)$$

Finally PDF of $\gamma_{r,t}$ is defined as:

$$p_{\gamma_{r,t}}(z) = \int_\kappa^\infty v p_{s_0}(vz) p_{s_1+\kappa}(v)dv = \int_\kappa^\infty \tfrac{v}{\sigma_0} e^{-\frac{vz}{\sigma_0}} \tfrac{1}{\sigma_1} e^{-\frac{v-\kappa}{\sigma_1}} dv \; = \; \frac{\kappa+\frac{1}{u}}{\sigma_0\sigma_1 u} e^{\left(\frac{\kappa}{\sigma_1} - u\kappa\right)} \qquad (8)$$

Probability that $\gamma_{r,t}$ is smaller than $w$ is defined as:

$$Pr\left(\gamma_{r,t} \geq w\right) = \int_w^\infty p_{\gamma_{r,t}}(z)dz = \frac{\sigma_0}{\sigma_0 + w\sigma_1} e^{-\frac{w}{\delta}} \qquad (9)$$

**Case 3**: more than one interferers are present in $I_r$ i.e. ($n_I > 1$) then PDF of $\sum_{i=1}^{n_I} s_i$ can be defined as:

$$p_I(v) = P_{\sum_{i=1}^{n_I} s_i}(v) \otimes p_{s_{n_I}}(v) = \sum_{i=1}^{n_I} \frac{b_i}{\sigma_i} e^{-\frac{v}{\sigma_i}} \qquad (10)$$

Here $b_i = \prod_{j=1, j\neq i}^{n_I} \left( \sigma_i \big/ \sigma_i - \sigma_j \right)$ $and \sum_{i=1}^{n_I} b_i = 1$. The PDF of term ($s_i$+k i.e. denominator of equ.2) is defined as: $p_{I+\kappa}(v) = p_I(v-\kappa)$. Finally the PDF of $\gamma_{r,t}$:

$$p_{\gamma_{r,t}}(z) = \int_{\kappa}^{\infty} v p_{s_0}(vz) p_{I+\kappa}(v) dv = \sum_{i=1}^{n_I} d_i \left( \frac{\kappa}{q_i} + \frac{\kappa}{q_i^2} \right) e^{-\kappa q_i} \qquad (11)$$

Here $q_i = \left( z \big/ \sigma_0 \right) + \left( 1 \big/ \sigma_i \right)$ and $d_i = \left( b_i \big/ \sigma_0 \sigma_i \right) e^{-\kappa q_i}$. Probability that $\gamma_{r,t}$ is smaller than $w$ is defined as:

$$Pr\left(\gamma_{r,t} \geq w\right) = \int_{w}^{\infty} p_{\gamma_{r,t}}(z) dz = \sigma_0 e^{-\frac{w}{\delta}} \sum_{i=1}^{n_I} \frac{b_i}{\sigma_0 + \sigma_i w} \qquad (12)$$

Finally Link Capacity can then be determined as:

$$c_{r,t}\left(I_r\right) = \sum_{i=1}^{\xi-1} c_i \square Pr\left(\gamma_{thr}^{i} \leq \gamma_{r,t} < \gamma_{thr}^{i+1}\right) + c_{\xi} \square Pr\left(\gamma_{r,t} \geq \gamma_{thr}^{\xi}\right)$$

Where $c_{r,t}(I_r)$ is average data rate between 't' and 'r', given interference set $I_r$ $c_{r,t}(I_r)$) $c_{r,t}(I_r)$

## IV. Proposed Time-Slot Assignment Algorithm

TDMA frame consists of a fixed number of slots is considered. The set of transmitting links that are activated in a given slot is called a **link pattern**, and the set of nodes activated in a given slot is called a **node pattern**.

### *A. Formulation of Node-Based Time-Slot Algorithm*

Notations:

V: set of nodes

E: set of links

NP: Node Pattern

$tx_e, rx_e;\ e \in E$ transmitter and the receiver of link e, respectively,

$E_{s,p} = \{e \mid e \in E, p \in s, s \in NP, tx_e = p\}$ set of links that can be used at node p, where p∈s i.e p is activated in node pattern *s*);

$\mu_s$ = portion of time that is assigned to node pattern (s) in a frame, where,

$\sum_{s \in NP} \mu_s = 1$

$\{\grave{o}_{s,p,e} \mid e \in E_{s,p}\}$ :portion of time that is assigned to each link of node p in node pattern s

F: set of flows in the system; where flow defines all traffic that belongs to (S, D) pair

$h_f$ : traffic demand for flow f, where $f \in F$

$S_f$ : source of flow *f*

$D_f$ : destination of flow *f*

$x_{f,e}$ : percentage of traffic that flow *f* passes through link e,

**Calculations**

**Link congestion:** it is total amount of traffic routed through the link 'e' over its average capacity ($c_e$) i.e. $r_e = \left( \sum_{f \in F} \frac{x_{f,e}}{c_e} \right)$ where link capacity (data rate between transmitter 't' and receiver 'r' is defined as: $c_e = \sum_{\{s | s \in NP, p \in s, e \in E_{s,p}\}} c_{s,e} \grave{o}_{s,p,e}$ .

Thus network congestion ratio 'r' is the maximum of all link congestion ratios, i.e. $r = \max_{e \in E} r_e$

Optimal node-based slot assignment scheme is one which minimizes congestion 'r':

$$\min \quad r \qquad (13a)$$

$$s.t \quad \frac{\sum_{f \in F} x_{f,e} h_f}{\sum_{\{e | s \in NP, p \in s, e \in E_{s,p}\}} c_{s,e} \grave{o}_{s,p,e}} \le r \quad (13b)$$

$$\sum_{\{e | e \in E_{s,p}\}} \grave{o}_{s,p,e} \le \mu_s \qquad (13c)$$

$$\sum_{\{e | p \in s, e \in E_{s,p}, rx_e = q\}} \grave{o}_{s,p,e} \le \mu_s \qquad (13d)$$

$$\sum_{s \in NP} \mu_s = 1 \qquad (13e)$$

$$\mu_s \ge 0, \grave{o}_{s,p,e} \ge 0, r \ge 0 \qquad (13f)$$

$$\sum_{\{e | tx_e = v\}} x_{f,e} - \sum_{\{e | rx_e = v\}} x_{f,e} = 0 \quad (13g)$$

$$\sum_{\{e | tx_e = S_f\}} x_{f,e} - \sum_{\{e | rx_e = S_f\}} x_{f,e} = 1 (13h)$$

$$x_{f,e} \ge 0 \qquad (13i)$$

Problem 13 is the optimization problem, whose purpose is to find the set of $\grave{o}_{s,p,e}$ that will lead to the optimal objective function. Constraint 13c represents that in node pattern s, for any node p∈s, p can transmit to only one node at one time. 13d ensures that a node q can receive from only one node at one time while q∉s and p∈s. 13f and 13i ensures non-negativity constraints. Constraint 13b is non-linear therefore $\mu_s r$ and $\grave{o}_{s,p,e} r$ are replaced by $\theta_s$ *and* $\rho_{s,p,e}$ respectively. Therefore final formulation is defined as:

$$\min \quad \sum_{s\in NP} \theta_s \qquad (14a)$$

$$s.t \quad \sum_{f\in F} x_{f,e} h_f \le \sum_{\{e|s\in NP, p\in s, e\in E_{s,p}\}} c_{s,e} \grave{o}_{s,p,e} \qquad (14b)$$

$$\sum_{\{e|e\in E_{s,p}\}} \rho_{s,p,e} \le \theta_s \qquad (14c)$$

$$\sum_{\{e|p\in s, e\in E_{s,p}, rx_e = q\}} \rho_{s,p,e} \le \theta_s \qquad (14d)$$

$$\theta_s \ge 0, \rho_{s,p,e} \ge 0 \qquad (14e)$$

$$\sum_{\{e|tx_e = v\}} x_{f,e} - \sum_{\{e|rx_e = v\}} x_{f,e} = 0 \qquad (14f)$$

$$\sum_{\{e|tx_e = S_f\}} x_{f,e} - \sum_{\{e|rx_e = S_f\}} x_{f,e} = 1 \qquad (14g)$$

$$x_{f,e} \ge 0 \qquad (14h)$$

Authors describe that the presented formulation can handle scheduling of node patterns by using Linear Programming approach. However for link based approach, listing all link patterns does not work by using LP formulation. Therefore column generation method is used to tackle the problem.

### *B. Frame Construction and Throughput Loss due to Frame Quantization*

Frame is constructed as: $n_f = \sum_{s\in NP} [z\mu_s]$ here z is frame length and function [x] rounds 'x' to nearest integer.

The frame quantization will change the portion of time assigned to all patterns ( $\mu_s$ ). Therefore parameters like minimum congestion ratio $r_z$, the optimal link capacities ($c_e$) and the routing scheme $x_{f,e}$

will change. These parameters need to be recomputed as follows. let $z_s$ be number of slots assigned to node pattern 's' in a frame.

$$
\begin{aligned}
\min \quad & \varsigma_z && (15a)\\
s.t \quad & \sum_{f\in F} y_{f,e} h_f \le \sum_{\{s|s\in NP,\, p\in s,\, e\in E_{s,p}\}} c_{s,e}\grave{o}_{s,p,e} && (15b)\\
& \sum_{\{e|e\in E_{s,p}\}} \grave{o}_{s,p,e} \le \frac{z_s}{\sum_{s\in NP} z_s} && (15c)\\
& \sum_{\{e|p\in s,\, e\in E_{s,p},\, rx_e=q\}} \grave{o}_{s,p,e} \le \frac{z_s}{\sum_{s\in NP} z_s} && (15d)\\
& \sum_{\{e|tx_e=v\}} y_{f,e} - \sum_{\{e|rx_e=v\}} y_{f,e} = 0 && (15e)\\
& \sum_{\{e|tx_e=S_f\}} y_{f,e} - \sum_{\{e|rx_e=S_f\}} y_{f,e} = h_f\varsigma_z && (15f)\\
& y_{f,e} \ge 0,\ \grave{o}_{s,p,e} \ge 0 && (15g)
\end{aligned}
$$

Here $\varsigma_z = 1/r_z$, $\mu_s = \left( z_s \Big/ \sum_{s\in NP} z_s \right)$, $y_{f,e} = \left( x_{f,e}/r_z \right) = x_{f,e}\varsigma_z$

### C. Column Generation Method

Column generation is an algorithm for solving large LP problems. Most of the variables are usually non-basic and assume zero values in the optimal solution, only a subset of variables are needed for solving the problem. Column generation method considers only the variables which have potential to improve the objective function. It splits the problem into master problem and subproblem. Master problem is the original problem with subset of variables being considered. In subproblem it uses duality approach to select new variables to be added to master problem to improve its result.

**Master Problem**: it is same as defined in problem 14 except that NP is replaced with $NP'$ (subset of NP which is feasible for 14). Solution of master problem shall provide a routing and slot-assignment scheme.

**Subproblem:** is a new problem created to identify a new node pattern to add to master problem and it is defined as:

$$\min_{s\in\{NP \setminus NP'\}} rp_s \qquad (15)$$

Here $rp_s$ is reduced cost of node pattern 's' in the column generation algorithm and it is optimal value of following problem:

$$\max\left(1-\sum_{\{p|p\in s\}}\omega_{s,p}-\sum_{\{q|p\in s,e\in E_{s,p},rx_e=q\}}\tau_{s,q}\right) \quad (16)$$

$$s.t \qquad \omega_{s,p}+\tau_{s,p}-\phi_e c_{s,e}\geq 0$$

Here $\omega_{s,p}$ $and$ $\tau_{s,q}$ are variables that are associated with the transmitter p and the receiver q in node patterns s. Well the question is which node pattern should be included into $NP'$?

According to duality theory if master problem is optimal then $rp_s$ is always non-negative for any pattern in NP. The node patterns with negative $rp_s$ can improve the result if they are added into $NP'$. So algorithm will iterate between two phases until no more patterns can be added to $NP'$.

Algorithm steps are defined as follows:

Step 1: Set node pattern A=$\phi$ and $rp_A$=0,

Step 2: Identify $A^c = v$ and compute $rp_{A'_v}$ for node pattern $A'_v$ $s.t$ $A'_v=\{A,v\}$.

Step 3: select $v$ from $A^c$ with minimum $rp_{A'_v}$ and compute $rp_A$ of A.

Step 4: If $rp_{A'_v}\geq rp_A$, node $v$ will be deleted from $A^c$ and add it A.

Step 5: If $A^c\neq\phi$ stop else go to step 3.

## V. Scheduling Algorithms

Two scheduling algorithms are proposed in which each node will locally schedule its link transmissions without inter-node coordination and without disturbing interference profiles of other nodes.

### A. Scheme 1

Every node ‘t’ in node pattern ‘s’ assigns a transmission probability to every link associated with ‘t’. The set of transmission probabilities is then defined as:

$$P_{s,t}=\left\{p_{s,t,e}\,|\,e\in E_{s,t},p_{s,t,e}=\frac{\grave{o}_{s,t,e}}{\mu_s}\right\} \qquad (17)$$

The region [0,1] is then divided into subregions, one for each link in $|E_{s,t}|$, and length of regions is set according to $P_{s,t}$. The algorithm works as follows; Suppose a node pattern ‘s’ is activated in slot $x$. Each node $t\in s$ will generate a RV $w$, uniformly distributed within [0, 1]. The node will then schedule link into which subregion $w$ falls. If selected link (e) is not usable (either due to fading or no traffic) the scheduler will check link next to 'e' one by one until a usable link is found.

### *B. Scheme 2*

Scheme 1 does not consider link quality while scheduling the links. Therefore authors presented another scheduling mechanism.

Selection criteria = (queue length * link capacity)

Each node maintains two queues for each of its link:

1) a real data queue to store packets and

2) A shadow queue for scheduling.

These queues of link 'e' whose transmitter can be activated in slot 'x', are defined as:

$$q_e(x) = q_e(x-1) + a_e(x) - d_e(x)$$
$$q'_e(x) = q'_e(x-1) + a'_e(x) - d'_e(x)$$

Here $q_e(x)$ and $q'_e(x)$ are lengths of the real queue and shadow queue respectively. $a_e(x)$, $a'_e(x)$, $d_e(x)$ and $d'_e(x)$ are the number of arrivals and departures for the two queues in 'x', respectively. In shadow queue the term $a'_e(x)$ is defined as: $a'_e(x) = \left(1 + {}^{v}\!/_{x}\right)\sum_{t=0}^{x} a_e(t)$ i.e. it is used to smooth the incoming traffic from source or previous hop.

Packets departing from link 'e' are defined as: $d_e(x) = \min\{\tilde{c}_e(x), q_e(x)\}$. Here $\tilde{c}_e(x)$ is instant capacity of link 'e' in slot 'x'. Thus scheduling, in slot 'x', the scheduler in node t∈s will select the link from all its associated links with a maximum value of $q'_e(x)\tilde{c}_e(x)$. In doing so, it tries to strike the optimal balance between link quality and traffic backlog.

## VI. SIMULATION AND RESULTS

### *A. Simulation Environment and Settings*

Linear optimization toolbox of MATLAB is used for proposed routing and slot-assignment algorithm. C++ program is then used to inspect maximum achievable throughput for different scheduling schemes.

The physical-layer parameters are summarized as follows:

- Transmission power: 20 dBm.
- Thermal noise:−90 dBm.
- Path loss(α):3.5.
- Variance of shadow fading: 4 dBm.

• Minimal distance of two nodes: 15 m.

• Slot duration: 0.22 ms.

• Frame size: 100 slots. So frame length = 22 ms.

The mapping between the following data rates and SINR threshold is summarized as follows.

• 54 Mb/s: 24.56 dBm.

• 48 Mb/s: 24.05 dBm.

• 36 Mb/s: 18.80 dBm.

• 24 Mb/s: 17.04 dBm.

• 18 Mb/s: 10.79 dBm.

• 12 Mb/s: 9.03 dBm.

• 9 Mb/s: 7.78 dBm.

• 6 Mb/s: 6.02 dBm.

**Network Topology:** two networks 15-node and 30-node with two gateway nodes and three gateway nodes are considered, respectively.

The traffic load of each flow is assumed to be the same i.e.,$h_f$ =1Mb/s,

**Throughput loss due to Frame Quantization:**

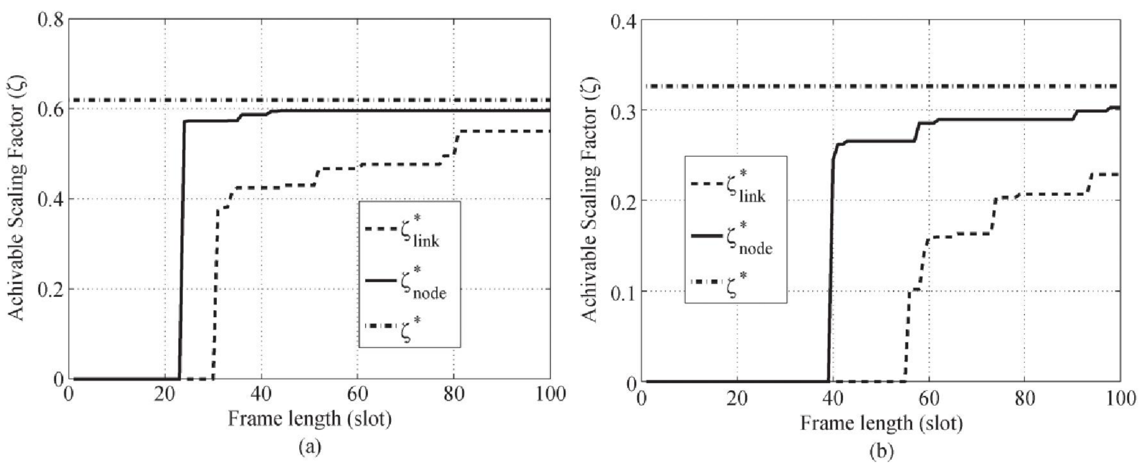


Fig. 1. Achievable throughput after frame generation for (a) 15- and (b) 30-node networks.

The solid ($\varsigma^*_{node}$), dashed ($\varsigma^*_{link}$) and dashed–dotted ($\varsigma^*$) lines indicate the achievable throughput in node-based, link based and before frame construction (I.e. upper bound on throughput) respectively. The flat area represents the range where the performance does not improve. Note that ($\varsigma^*_{node}$) and ($\varsigma^*_{link}$) are function of 'z' and are not always monotonically increasing due to the quantization involved in the process, and small oscillation occurs within a short range of z. This is why, in Fig. 1(a) and (b), the curves move up in steps.

TABLE I
PERFORMANCE COMPARISONS FOR THE LINK- AND NODE-BASED SCHEMES

| $N$ | $\zeta^*$ | $\zeta^*_{node}$ ($\zeta^*_{link}$) | $n_{use}$ | $\zeta^*_{exp,1}$ | $\zeta^*_{exp,2}$ | $\zeta^*_{det,1}$ | $\zeta^*_{det,2}$ |
|---|---|---|---|---|---|---|---|
| 15 (Node) | 0.62 | 0.60 | 17 | 0.62 | 0.77 | 0.62 | 0.76 |
| 15 (Link) | 0.62 | 0.55 | 26 | NA | NA | NA | NA |
| 30 (Node) | 0.33 | 0.30 | 30 | 0.31 | 0.39 | 0.31 | 0.39 |
| 30 (Link) | 0.33 | 0.23 | 54 | NA | NA | NA | NA |

From the table it is clear that $\varsigma^*_{node}$ approaches $\varsigma^*$ much faster than $\varsigma^*_{link}$. Moreover difference in throughput between $\varsigma^*_{node}$ and $\varsigma^*_{link}$ is also significant as shown in table 1.

The optimal scaling factors of the $\varsigma^*_{node}$ for schemes 1 and 2 under the Poisson and a deterministic arrival process are denoted as shown by $\varsigma^*_{\exp,1}$, $\varsigma^*_{\exp,2}$, $\varsigma^*_{\det,1}$, $\varsigma^*_{\det,2}$ respectively.

{the $\varsigma^*_{node}$ is derived from problem 14 and it does not include multi-user diversity gain. Therefore, it can be viewed as a lower bound of the two proposed scheduling schemes 1 and 2 As shown in the Table I.

It is also clear from the table that , both (posisson and deterministic arrival rates )$\varsigma^*_{\exp,1}$, $\varsigma^*_{\det,1}$ are only slightly larger than $\varsigma^*_{node}$ for the 15- and 30-node networks. The difference is only about 3%. This is because scheme 1 tries to follow $\grave{o}_{s,p,e}$ i.e. portion of time that is assigned to each link of node p in node pattern s and does not select a link with the best quality. However, the situation is different in scheme 2, because link quality is part of the selection criteria. With scheme 2, $\varsigma^*_{\exp,1}$, $\varsigma^*_{\det,1}$ are about 26% larger than $\varsigma^*_{node}$ for the 15-node network and 30% larger for the 30-node network.