Transmission Probability-based Dynamic Power Control for Multi-Radio Mesh Networks

T. O. Olwal, F. Aron, B. J. van Wyk, Y. Hamam, N. Ntlatlapa and D. Johnson

Abstract—This paper presents an analytical model for the selection of the transmission power based on the bi-directional medium access information. Most of dynamic transmission power control algorithms are based on the uni-directional channel and interference state information. Such studies consider energy-constrained networks with the need to increase the battery life and improve QoS. In this paper we propose a distributed dynamic power control solution based on the knowledge of the PHY and MAC layers' local information for multiple radio WMNs. Each radio interface/link is modelled individually in order to reduce system complexity. The design involves the derivation of a MAC based transmission scheduling probability (MAC-TSP). The transmission power is dynamically adjusted in response to the MAC-TSP measurements in each time slot. Simulation results show that average throughput performance for each radio link can be improved significantly when sufficient MAC information is available to the power control system.

Index Terms—Distributed Dynamic Power Control, MAC-Transmission Scheduling Probability, Multiple Access Interferences, PHY-layer aspects, Wireless Mesh Networks.

I. INTRODUCTION

Wireless Mesh Networks* (WMNs) are multi hop networks composed of wireless mesh routers (WMRs) forming the backbone mesh and wireless mesh clients (WMCs) forming the client mesh. WMCs are capable of networking amongst themselves and with WMRs [1]. WMRs may be considered to have minimal mobility and are capable of forwarding mesh client traffic to the internet gateways through multiple hops. On the other hand, WMCs are either stationary or mobile and can provide access for users to the mesh network [3]. Each WMR may be equipped with multiple interfaces (radios) and multiple channel capabilities [2] for throughput and scalability enhancement [3]. WMNs are thus, capable of dynamically self-healing, self-configuring and self-organising in response to internal or external network dynamics [4]. Such dynamics are as a result of fluctuations in battery power levels, links' faults and failures, node mobility, traffic load imbalances and co-channel and adjacent multiple access interferences (MAI). The effects of such dynamics are unlimited network disjoints (or the creation of network dead zones) [5], throughput and quality of service (QoS) degradations [6], [7]. Motivated by the low upfront costs, the attractive structural and functional features, WMNs have been proposed for rural community owned broadband applications [3], [4]. However, in rural areas the problem of power supply is a critical limitation [3], [7]. The benefits of power control are not only the increased battery life but also the improvement of desired QoS and the mitigation of effective network interference. Power control may increase the overall network capacity by allowing higher frequency reuse [8]. Because of the distributive nature of the wireless mesh network and structural complexities, it is essential to study a distributed dynamic transmission power allocation (DDPCA) problem.

Distributed power control problems in wireless networks have been widely studied in the context of Cellular, Ad Hoc and Sensor networks [9]-[22] (and references therein). However, these studies apply to conventional WMC networks with single radio interface functionalities [10], [9], [18], [22]. Furthermore most of considerations focus on the energy constrained (size limited) devices and the need to increase the battery life and desired QoS [19] while treating throughput maximization as a secondary problem [21], [22]. The improvement of QoS has been recently achieved through distributed greedy power control algorithms [9]-[22]. That is, the transmission power is injudiciously increased in order to achieve a specific target QoS at the intended receiver. There are several drawbacks associated with such algorithms. First, increasing transmission power greedily may result in faster energy depletion in that node. Second, the increasing of the transmission power may cause excessive interferences to multiple network users considering CDMA systems. Third, increasing transmission power limits frequency re-use resulting in throughput degradation.

In this paper we investigate the impact of a transmission scheduling probability (TSP) of any medium access control (MAC) protocol on the design of power control. The MAC-TSP is essential to provide a payoff needed for the choice of power for transmission attempts. The work in [18], [16] considered a carrier sense multiple accesses with collision avoidance (CSMA/CA) MAC protocol for power control. However, CSMA/CA based systems offer low network capacity [27] and do not guarantee minimal power levels [17]. We consider a minimization power control problem related to the work in [15], [17]. For instance, the authors in [15] investigated the impact of autonomous interference estimation on the dynamic power control (AIPC). The authors proposed both user centric and network centric

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objective minimization problem. The user centric minimization problem was solved through a greedy algorithm and the network centric minimization problem was solved through energy-efficient algorithm [7]. However, the proposed method assumes one hop communication in a cellular network setting and the multiple access interferences (MAI) are modelled at a centralised base station. In [17], a joint scheduling and power control for multicast traffic is studied. Each sender maintains or defers its multicast connections based on the impact of MAI on the desired QoS. Although, the algorithm indicates superb performance for multicast admission control, the algorithm relies on MAI information. In this paper we have shown that throughput can be improved significantly when a scheduling system has adequate information about multiple medium accesses. That is, we investigate the impact of channel state, MAI, PHY-layer aspects such as modulation and coding on successful packet reception (SPR) when considering a per link transmission power.

The paper is organised as follows. In section II, a motivation and assumptions of the system model are presented. The problem is formulated in section III. Section IV presents and discusses the simulation results. In section V, the paper is concluded.

II. MOTIVATION AND ASSUMPTIONS

Consider a wireless mesh network composed of stationary backbone nodes. Radio interfaces access the channel by using a distributed time-slotted scheme [24] with a fixed time slot duration, which accounts for a power control adjustment mini-slot time, a packet transmission mini-slot time and a guard time interval. Through CDMA schemes, active radio links cause co-channel interferences at target receivers. The CDMA scheme employing orthogonal code sequence is preferred because of its anti-jamming capabilities, robustness to multiple path effects and low spectrum density in multiple users' access environment. The adjacent channel interferences (ACI) may be assumed insignificant [25]. Wireless channels can be assumed to hold their states constant in one slot duration, but may be changing in the long run. Such information can be obtained by the sender link either through direct measurement (where time slots are assumed to be long in comparison of measurement time) or a combination of measurement and channel prediction. We consider that each radio link will measure and predict autonomously its interference channel state and the MAC-TSP in each time slot [26].

The network model can be described with a directed graph $G(V,E)$, where vertices V, represent radio devices and edges E, represent physical links. The signal to interference plus noise ratio (SINR) at receiver device r when a signal is transmitted by sender device i in time slot k is given by

$$\beta_{irk}(p) = \frac{S_i \; p_{ir}(k) G_{ir}(k) x_{ir}(k)}{\sum_{(l,m)\neq(i,r)} p_{lm}(k) G_{lr}(k) x_{lm}(k) + \eta_r}, \qquad (1)$$

where S_i is the spreading gain (or the bandwidth expansion factor) of the spread-spectrum system, $p_{ir}(k)$ is the transmission power emitted by i on link (i,r), $G_{ir}(k)$ is the gain of the radio channel between i and r, η_r is the thermal noise at receiver r, and $x_{ir}(k)$ is an on/off indicator, i.e.,

$$x_{ir}(k) = \begin{cases} 1 \text{ if device } i \text{ transmits to device } r \\ \quad \text{in time slot } k, \\ 0 \; \textit{otherwise} \end{cases} . \qquad (2)$$

At each receiver, the measured multiple access interference plus noise (MAI) is denoted as

$$\psi_{-(i,r)}(k) = \sum_{(l,m)\neq(i,r)} p_{lm}(k) G_{lr}(k) x_{lm}(k) + \eta_r . \qquad (3)$$

where $-(i,r)\in E$ refers to interfering links other than the link $(i,r)\in E$. The reliability of the noisy measurements for the MAI in (3) can be improved through filtering. A robust filter for predictive power control algorithm has been proposed in [26]. In addition to the MAI information, the PHY-layer aspects namely, modulation, coding and transmission power must be known for a successful reception of a user packet. The probability of successful reception by a user link $(i,r)\in E$ conditioned on the activity of other network users is given by [23],

$$\begin{aligned} q_{irk}(p) &= P\{\textit{successful packet reception}\}, \\ &= \sum_n P\{\textit{successful packet recept}, C_{ir}(k) = c_{irn}\}, \\ &= \sum_n P\{\textit{succ. packet recept} \mid C_{ir}(k)\} P\{C_{ir}(k) = c_{irn}\}, \\ &= \sum_n f_{irn}(p) P\{C_{ir}(k) = c_{irn}\}, \end{aligned} \qquad (4)$$

where $f_{irn}(p)$ is a PHY-layer function of transmission power p for link $(i,r)\in E$ at time k. In terms of SINR [28], [23], $f_{irn}(p)$ is given as

$$f_{irn}(p) = \{1 - P_b[\beta_{irk}(p)]\}^{\ell}, \qquad (5)$$

where $P_b[.]$, denotes the bit error rate (BER) and ℓ is the length of the PHY-layer convergence protocol data unit (PPDU). Whereas $P\{C_{ir}(k) = c_{irn}\}$ denotes the probability that a time-variant random variable $C_{ir}(k)$ has a realization c_{irn}. According to (2), multiple transmissions indicate a Bernoulli-distribution with probability τ_{lm}. This τ_{lm} models the probability that a link *lm* will attempt a successful transmission at any time according to any medium access control (MAC) protocol in place. This implies that $P\{C_{ir}(k) = c_{irn}\}$ can be given by,

$$P\{C_{ir}(k) = c_{irn}\} = \prod_{u \in c_{irn}} \tau_u \prod_{w \in \bar{c}_{irn}} (1 - \tau_w), \qquad (6)$$

where $\bar{c}_{irn}$ denotes those links that are not transmitting concurrently with link $(i,r)\in E$, i.e., the compliment set of the combination of interferers $\{c_{irn}\}_{n=1,2,3,\ldots,2^{Nr-1}}$. However, the expression in (4) can be modified to eliminate asymmetry of wireless links i.e., $G_{ir} \neq G_{ri}$ and create a bi-directional link. The bi-directional link enhances reliable multiple hops' connectivity. In what follows, two events need to happen for a link (i,r) to consider its transmission to be successful: the successful reception of a channel probing packet at device r, and the successful reception of acknowledgement packet at device i. Thus, (4) becomes

$$q_{irk}(p) = \sum_n \sum_l f(c_{irn}) f(c_{ril}) P\{C_{ir}(k)=c_{irn}\} P\{C_{ri}(k)=c_{ril}\}. \tag{7}$$

Equation (6) depicts that $\tau_{irk}(p)$ is a non-linear dynamic function of $q_{irk}(p)$, i.e., $\tau_{irk}(p) = f(q_{irk}(p))$. In order to consider a linear problem, we will assume that $\tau_{irk}(p)$ has a continuous *n*th derivative throughout the interval [0, 1]. The corresponding Maclaurin series expansion is given by

$$\begin{aligned}\tau_{irk}(p) &= f_{irk}(0) + q_{irk}(p) f_{irk}^{/}(0) + \ldots + q_{irk}^{n}(p) f_{irk}^{(n)}(0)/n! \\ &\cong f_{irk}(0) + q_{irk}(p) f_{irk}^{/}(0) \\ &\approx f_{irk}^{/}(0) q_{irk}(p) \\ &= \phi\, q_{irk}(p),\end{aligned} \tag{8}$$

where ϕ is a function of the number of multiple activities in the neighbourhood of the sender link $(i,r) \in E$.

If we consider that initially each link evaluates the signalling information in (8) by using a probing power *p*, then the DDPCA policy is given by the gradient function:

$$\frac{\partial p_{irk}(t)}{\partial t} = \alpha_{irk}(t) \tau_{irk}(p), \quad \forall t \in \{0,1,\ldots,I_k\}, \quad \forall k \in \{1,2,\ldots,K\}, \tag{9}$$

$$\Rightarrow p_{irk}(t+1) - p_{irk}(t) = \alpha_{irk}(t) \tau_{irk}(p),$$

$$p_{irk}(t+1) = p_{irk}(t) + \alpha_{irk}(t) \{\tau_{irk}(p)\}. \tag{10}$$

Here, the equation (10) depicts an adaptive transmission power execution in each active link at the *k*th time slot based on imperfect MAC-TSP measurements. The notation $\alpha_{irk}(t)$ represents the distributed power controller gain at instantaneous time t (i.e., $t \le k$). In section III-B we show that optimal gain $\alpha_{irk}(t)$ is obtained by minimising an objective function. If we consider, slow shadowing and fading processes and that MAI hold their state in each time slot then the measurement of the MAC-TSP can be taken once in every time slot k. This implies that the power updating process is dynamically performed a slot-by-slot. However, at least one packet must be transmitted in each time slot assuming high transmission rates in WMNs [1].

III. MATHEMATICAL FORMULATION

A. *System Cost Function*

In the context of distributed cross-layers interaction between the PHY and MAC layers, we consider that each active independent interface device performs the policy in (10) so that its received SINR is at least the target SINR and the predicted aggregate MAI level is minimal. However, due to conflicts in benefits perceived, a greedy link will experience a low MAC-TSP *payoff.* Such link will then be forced to lower its transmission power to attain network power stability. On the other hand the overly energy-efficient device will also experience a low bit delivery ratio *payoff* and will then be encouraged to attempt transmission in order to improve its MAC-TSP payoff. The objective function minimising the next time slot SINR deviation and the predicted aggregate MAI for each link is

$$\min J_{(i,r)\in E}(k), \quad \forall k \in \{1,2,\ldots,K\} \tag{11}$$

where $J_{(i,r)\in E}(k) = \omega_{ir1}\, \varepsilon_{ir}^2(k+1) + \omega_{ir2}\, \psi_{ir}^2(k+1)$ [15].

Here, the SINR deviation between the sender device i and the receiver device r at the next time slot is

$$\varepsilon_{ir}(k+1) = \gamma_{ir} - \beta_{ir}(k+1), \tag{12}$$

and the aggregate MAI at the next time slot is given by

$$\psi_{ir}(k+1) = \psi_{-(i,r)}(x_{lm}(k+1)) + p_{ir}(k+1) G_{ir}(k+1). \tag{13}$$

B. *System Constraints*

The cost function in (11) must be minimised subject to the following constraints:

$$x_{irk} \in \{0,1\} \qquad \forall (i,r) \in E, \ k = 1,\ldots,K. \tag{14}$$

$$\sum_{(i,r)\in E} x_{irk} + \sum_{(r,i)\in E} x_{rik} \le 1 \qquad \forall i \in V, \ k = 1,\ldots,K. \tag{15}$$

$$0 < \tau_{irk}(p) \le 1 \qquad \forall (i,r) \in E, \ k = 1,\ldots,K. \tag{16}$$

$$\left\{\frac{d_{ir}}{R_T^{Max}}\right\}^{\rho} . P_{ir}^{Max} . x_{ir}(k+1) \le p_{ir}(k+1) \le P_{ir}^{Max} . x_{ir}(k+1). \tag{17}$$

$$\sum_u p_{iru}^{Max} \le p^{Max} \quad . \tag{18}$$

Here, Constraint (14) is a binary constraint that models concurrent transmission of link (i,r) with other links in the network. Constraint (15) implies that each radio device is active in at most one link in each slot, while constraint (16) implies that the MAC-TSP is a zero-one bounded. Equation (17) is the necessary condition for a successful transmission. That is, a receiving device r must fall within the transmission range of the sender device i. The parameters, ρ, d_{ir}, R_T^{Max} and R_I^{Max} are the path-loss exponent, transmission distance on link(i,r), the maximum transmission and interference ranges, respectively. Proof for equation (17) is straight forward by extending analytical results in [27]. The lower bound for equation (17) offers a practical minimum power level for channel probing scheme [14]. Constraint (18) implies that the sum of specified maximum powers for all interfaces must be at most the maximum transmission power limit in each node. Finally, it can be shown that the optimal control gain, $\alpha_{ir}^{*}(k)$ derived from the objective function, is a function of the predicted version of the filter output and the TSP.

Corollary 1: For a link executing the power iteration in (10), the optimum controller gain $\alpha_{ir}^{*}(k)$ *in the* k*th iteration can be given as shown*

$$\alpha_{ir}^{*}(k)=\frac{A_k-\omega_{ir}\,\psi_{-(i,r)}^{2}(k+1)\left\{\psi_{-(i,r)}(k+1)+p_{ir}(k)G_{ir}(k)\right\}}{B_k\left\{1+\omega_{ir}\,\psi_{-(i,r)}^{2}(k+1)\right\}}, \tag{19}$$

where

$$A_k=\psi_{-(i,r)}(k+1)\gamma_r-p_{ir}(k)G_{ir}(k), \tag{20}$$

$$B_k=G_{ir}(k)\{\tau_{irk}(p)\}. \tag{21}$$

$$\omega_{ir}=\omega_{ir2}/\omega_{ir1}. \tag{22}$$

Here, γ_{ir} and ω_{ir} are respectively, the target SINR threshold and the non-negative weight factor for the objective function minimization.

Proof: The outline of the proof is as follows: Substitute (10) into equations (12) and (13), and then differentiate (11) with respect to $\alpha_{ir}(k)$. Set the result to zero and simplify to get (19). In section IV, simulation results show that $\alpha_{ir}^{*}(k)$ must be a non-zero real number in the execution of a dynamic power control in response to MAC-TSP feedback.

C. *Power Control Algorithm*

We consider that in the *k*th time slot, there can be mini-time slots for channel signalling and power iteration execution

The outline of the power control algorithm is as follows:

1) Initially all interface devices are assumed active, i.e., there are packets in each queue waiting to be transmitted.
2) Initially the feasible set is empty, i.e., no radio link has optimal power level that satisfies the objective function in (11).
3) Each active radio link, say link l_{ir}^{a}, measures its thermal receiver noise, i.e., η_r.
4) Each active radio link, say link l_{ir}^{a}, measures its direct channel gain, i.e., G_{irk}.
5) Each active radio link, say link l_{ir}^{a}, draws an independent uniform random variable to select an initial (probing) power level. If an integer parameter *Q* represents the total number of power levels to which a transmitter can be adjusted then,

$$\vec{P}_{uniform}(0)=\left\{\frac{1}{Q}p_{ir}^{Max},\frac{2}{Q}p_{ir}^{Max},\ldots,p_{ir}^{Max}\right\}. \tag{23}$$

   Such random choice helps in resolving starvation conflicts [19]. In a special case link l_{ir}^{a} computes the lower bound in the constraint (17) as its probing power. The probing power helps a link to exchange cross-layers signalling information with its neighbours[†].
6) Each radio link, say link l_{ir}^{a}, measures, estimates and predicts through a robust filter implemented in [26], the perceived multiple access interference.
7) Each radio link, say link l_{ir}^{a}, computes its scheduling rate (TSP), i.e., as in (8). At this stage if a link's TSP is zero then that link goes on power-save mode, i.e., selects a zero transmission power.
8) Each radio link, say link l_{ir}^{a}, computes the received SINR, i.e., as shown in (1).
9) Each radio link, say link l_{ir}^{a}, executes optimal power iterations. In this phase each link selects a zero weighting factor and executes power iteration in a greedy fashion. If the iteration converges within a predefined mini-time slot, then DATA packets are transmitted in the next mini-time slot. However, if a link's power iteration fails to converge within the predefined mini-time slot then, that link selects a non-zero weighting factor and defers its transmissions for a random time interval. A deferring link must resolve starvation conflicts and gain the admission rights into the network by repeating steps (5) to (9).

IV. PERFORMANCE EVALUATION

To investigate performance of the analytical model, we used MATLAB™ version 7.1, to simulate realistic physical layer aspects and MAC layer model which are often simplified in idealized network simulators. A random network topology was assumed. Simulation parameters were assumed as shown in Table I. Each interface device was specified with a maximum transmission range of 50 m and interference range of 100 m to guarantee multiple hop communications. We assumed typical carrier frequency of 5.2 GHz in order to calculate the time-varying channel gain, whereas, bandwidth, differential modulation, and coding techniques were used as in [28]. Performance metrics were evaluated by Monte Carlo simulations for 60 independent runs for each random network configuration (instance).

TABLE I
SIMULATION PARAMETERS

Parameters	*Specifications Values*
Number of Nodes	50 each with 3 interfaces
Deployment Area	1000 m X 1000 m
P*min*, P*max* per radio link	0 mW, 100 mW
Medium access (MAC) probing power per link	Variable, P*min* < P*prob* < P*max*
Medium Access Control	Time-slotted CDMA
Slot duration, Packet Duration	100 msec, 80 msec
Packet Arrival rates/interface	12.8,51.2,89.6,128 pkts/s
Packet size, path-loss factor	1000 bytes, 4
Thermal noise, Target SINR	10e-6 mW, 5
Simulation time	60 s

Fig. 1 shows the impact of autonomous adjustment of the transmission power on the bit reception probability at different network traffic loads. Assuming independent MAI at each sender receiver, the bit delivery ratio-power curve is a monotonically increasing curve. Such observation depicts a greedy algorithm in which case, each link strives to increase its transmission power in order to attain a reliable connection with its receiver. If the MAI and the traffic arrival rates are low then increasing the sender power yields successful bit delivery ratio. However, the bit delivery ratio

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[†] In practice, each device initially probes its neighbours for clear channel information (CCI) and this is usually performed at maximum power [5], this work proposes an iterative probing scheme with transmission power adjusted dynamically in every forward-backward time.

degrades for a high network traffic load. This implies that at high arrival rates, there are high interferences and collisions that degrade the bit reception probability. Similar observation can be reported for results in Fig. 2. That is, Fig. 2 shows that at different packet level arrival rates, the packet delivery ratio-transmission power curve is monotonically increasing. However, power demand is high to send packets reliably to the receiver, i.e., with high successful delivery probability. In particular, over 20 mW, 40 mW and 60 mW of transmission power were needed, respectively to transmit 51.2, 89.6, 128 packets/s of the traffic load.

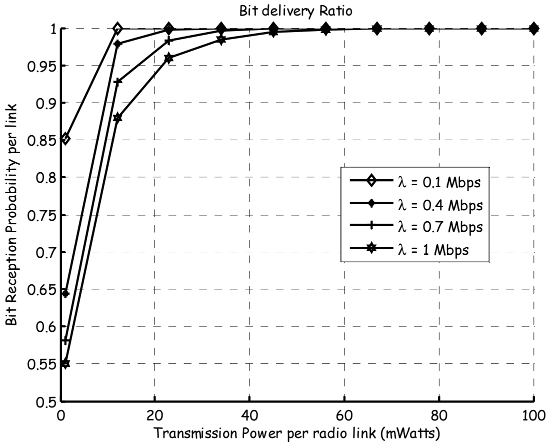

Figure 1: Bit delivery rate as a function of transmission power

In Fig. 3, the impact of changes in the medium access control (MAC) probability (MAC-TSP) on the autonomous link optimal power control gain at different objective function weight factors is shown. At different transmission scheduling probabilities, each interface autonomously chooses the value of the weight factor from a non-negative real range and determines a stable level for optimal dynamic power execution gain (ODPCG). In each time slot the dynamic transmission power is executed until steady state. At the beginning an interface uses a probing power to gather various local network information including interference, channel conditions and PHY-layer aspects. The interface then determines the MAC-TSP information. The reliability of the MAC-TSP depends on the conditions of wireless channel at any given time. If the MAC-TSP is low then the wireless channel condition is an unreliable for successful transmission and vice versa. At a zero weighting factor, Fig. 3 shows that the ODPCG falls rapidly from a high positive value to a near zero level, i.e., defined as stable region as the MAC-TSP increases. This implies that, the ODPCG tracks the channel uncertainties exponentially fast in order to reach the stable region. However, at a unity weighting factor, *a marginal* gain response was noted, i.e., the ODPCG falls from a sufficiently large positive value to a negative region and rises monotonically to a stable level. If the weighting factor was taken to be a large positive then the ODPCG-MAC-TSP curve rises monotonically from a large negative to a stable region. The observations are due to the fact that, an interface decision to select a zero weighting factor allows such interface to autonomously attain its desired QoS in a time-competitive environment. It is thus, a desirable decision for delay-sensitive QoS applications such as voice traffic. However, the decision faces high energy depletion cost. On the other hand deciding on a non-zero weighting factor implies that the primary goal to conserve individual energy and to reduce overall network interferences. Such decisions are tolerable by data traffic applications. However, energy-saving decisions may face starvation conflicts, particularly when a device fails to resolve its starvation problem in a number of transmission trials. The impact of this is the increased queue congestions.

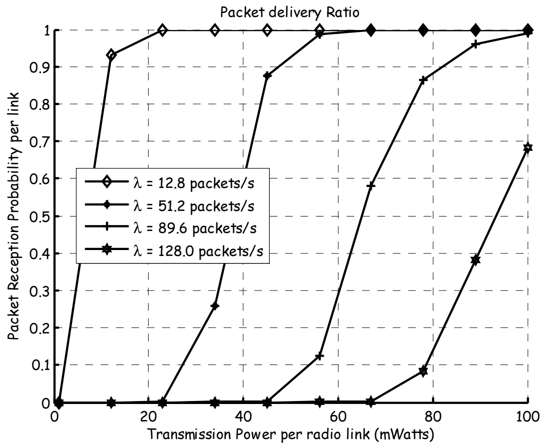

Figure 2: Packet delivery rate as a function of the transmission power

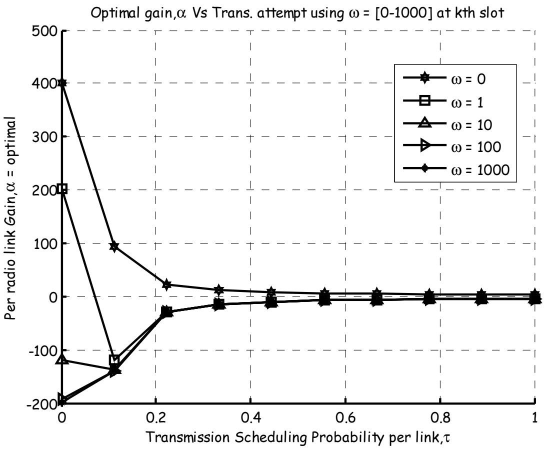

Figure 3: Optimal dynamic power control gain as a function of transmission scheduling probability

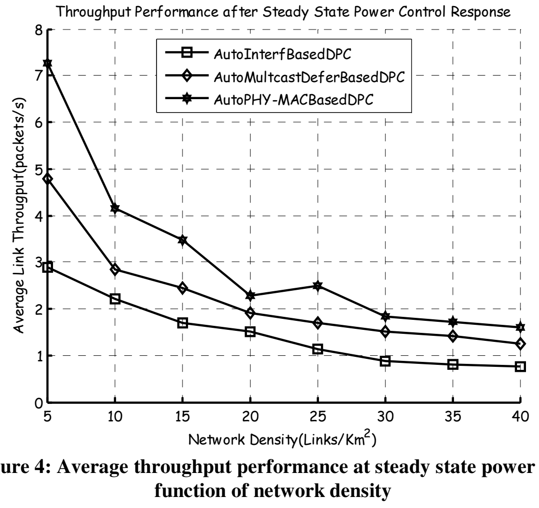

Figure 4: Average throughput performance at steady state power as a function of network density

Figure 4, reveals the average link throughput performance with respect to the network density assuming the same deployment area. In the simulation, fixed locations of source devices and destination devices were predetermined. The average steady state transmission power was used to send DATA packets between any two sender-receiver pair in a local neighbourhood. Sources which could not reach their destinations when using steady state transmission power did so through multiple hop packet forwarding by intermediate hops. The rate of packets that successfully reached the intended destination was measured and considered as the average link throughput. The same simulation environment was run for multiple interference estimation-type algorithms for a unicast and multicast traffic connections.

The simulation results show that the average throughput performance degrades as the network becomes denser. This implies that collisions and interference are more likely when the network density grows large. However, if each link has sufficient medium access information then throughput can be improved significantly. In other words the choice of optimal transmission power to use for a reliable successful reception depends on the PHY-layer parameters and concurrent activity of the network in the neighbourhood. Simulation results show that MAC-TSP information-based power control improves throughput performance compared to some conventional algorithms.

V. CONCLUSION

In this paper MAC-TSP information model was presented to improve the dynamic power control assuming a time-slotted CDMA system. The contribution in the work is that due to complexities, multiple radio interfaces transmissions can be modelled individually. Earlier works on power control have considered a single radio modelling approach with MAI and wireless channel conditions as the available information for DDPCA. However, throughput performance can be improved by presenting sufficient local medium access information to the power control system. Such medium access information is functions topology and the PHY-layer aspects. However, acquiring sufficient local information may introduce overheads and undesirable delays in the network. Such impairments are subject of the future work.

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