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Enhancing Downlink Performance in Wireless Networks

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ABSTRACT: In this paper we consider using simultaneous MultiplePacket Transmission (MPT) to improve the downlink performance of wireless networks.Wealso give analytical bounds for maximum allowable arrivalrate which measures the speedup of the downlink after enhanced with MPT and our results show that the maximumarrival rate increases significantly even with a very smallcompatibility probability. We also use an approximate analytical model and simulations to study the average packetdelay and our results show that packet delay can be greatlyreduced even with a very small compatibility probability

KEYWORDS-Multiple packet transmission, wireless LAN,matching, approximation algorithm, maximum allowablearrival rate, delayMultiple packet transmission, wireless LAN, matching, approximation algorithm, maximum allowablearrival rate, delay.

I. INTRODUCTION

Traditionally, in wireless networks, it's miles assumed that onedevice can send to simplest another device at a time. However, this restrict is not proper if the sender has greaterthan one antennas. By processing the records in keeping with thechannel state, the sender could make the records for one user seem as zero at other users such that it can send wonderfulpackets to wonderful users concurrently. We call it Multiple Packet Transmission (MPT) and will explain the infoof it in Section 2. For now, we need to point out the profound effect the MPT technique has on wireless LANs. Awireless LAN is typically composed of an Access Point (AP)that is linked to the stressed out community and numerous users which communicate with the AP via wi-fi channels. In wireless LANs, the maximum commonplace type of traffic isthe downlink visitors, i.e., from the AP to the users whilst the users are browsing the Internet and downloading data. In these days'swi-fi LAN, the AP can send one packet to at least one personat a time. However, if the AP has two antennas and if MPTis used, the AP can ship two packets to 2 users every timeviable, for this reason doubling the at some point of of the downlink inthe suitable case.MPT is feasible for the downlink because it is not difficult to equip the AP with two antennas, in fact, manywireless routers today have two antennas. Another advan-tage of MPT which makes it very commercially appealingis that although MPT needs new hardware at the sender, itdoes not need any new hardware at the receiver. This meansthat to use MPT in a wireless LAN, we can simply replacethe access point and upgrade software protocols in the userdevices without having to change their wireless cards, andthus incurring minimum cost.

In this paper we study problems related to MPT and provide our solutions. We formalize the problem of sendingout buffered packets in minimum time as finding a maximum matching in a graph. Since maximum matching algorithms are relatively complex and may not meet the speedof real time applications, we consider using approximationalgorithms and present an algorithm that finds a matchingwith size at least 3/4 of the size of the maximum matching in $O(|E|)$ time where $|E|$ is the number of edges in thegraph. We then study the performance of wireless LAN enhanced with MPT and give analytical bounds for maximumallowable arrival rate. We also use an analytical model andsimulations to study the average packet delay.

Enhancing wireless LANs with MPT requires the Media Access Layer (MAC) to have more knowledge about thestates of the physical layer and is therefore a form of crosslayer design. In recent years cross-layer design in wirelessnetworks has attracted much attention because of the greatbenefits in breaking the layer boundary. For example, [5, 6]considered packet scheduling and transmission power control in cross-layer wireless networks. However, to the bestof our knowledge, packet scheduling in wireless networksin the context of multiple packet transmission has not beenstudied before. [3, 4] have considered Multiple Packet Reception (MPR) which means the receiver can receive morethan one packets from distinct users simultaneously. MPRis quite different from MPT since MPR is about receivingmultiple packets at one node while MPT is about sendingmultiple packets from one node to multiple nodes.

II. BACKGROUND WORKS

The AP keeps the record for the channel coefficientvectors of all nodes that have been reported to it previously.If, based on the past channel coefficient vectors, U1 and U2are likely to be compatible and there are two packets thatshould be sent to them, the AP sends out a Require To Send(RTS) packet, which contains, in addition to the traditionalRTS contents, a bit field indicating that the packet about tosend is an MPT packet. If U1 appears earlier than U2 in thedestination field, upon receiving the RTS packet, U1 willfirst reply a Clear To Send (CTS) packet containing thetraditional CTS contents plus its latest channel measurements. After a short fixed amount of time, U2 will also replya CTS packet. After receiving the two CTS packets, the APwill update their channel coefficient vectors. It will thendecide whether U1 and U2 are still compatible, and if so, the
AP will send two packets to them. If in the rare case that thechannels have changed significantly such that they are nolonger compatible, the AP can choose to send to only onenode. Therefore, before sending the data packets, the APfirst sends 2 bits in which bit i is "1" means the packet for Ui will be sent. After the data packet is sent, U1and U2 can reply an acknowledgment packet in turn.

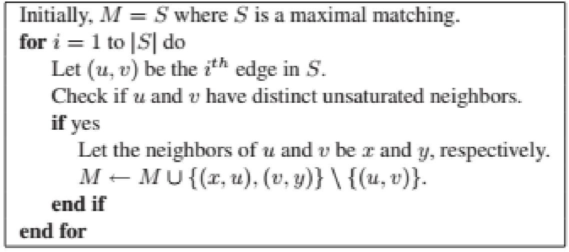
III. PROPOSEDWORK

The simplest and most well known approximation algorithm for maximum matching simply returns a maximalmatching. It is known that this simple algorithm has O(|E|)time complexity where |E| is the number of edges in thegraph and has a performance ratio of 1/2, which means thatthe matching it finds has size at least half of M ∗ whereM ∗ denotes the maximum matching. In this section wegive a simple O(|E|) approximation algorithm for maximum matching with an improved ratio of 3/4. To the bestof our knowledge it is the first linear time approximationalgorithm for maximum matching with 3/4 ratio.

A. Eliminating Augmenting Paths of Length 3

We start with a maximal matching denoted by S and theoutput of our algorithm is denoted by M. For each vertex,a list is used to store its neighbors. An array is used tostore the matching, that is, the ith element in the array is thevertex matched to the ith vertex. Note that with this array,it takes constant time to augment the matching with fixedlength augmenting paths or to check whether a particularvertex is saturated or not.The algorithm is summarized in Table 1. Initially, letM = S. We will check edges in S from the first to thelast to augment M. When checking edge (u, v), we checkwhether both u and v are adjacent to some distinct unsaturated vertices.

Table 1. Finding Augmenting Paths of Length 3



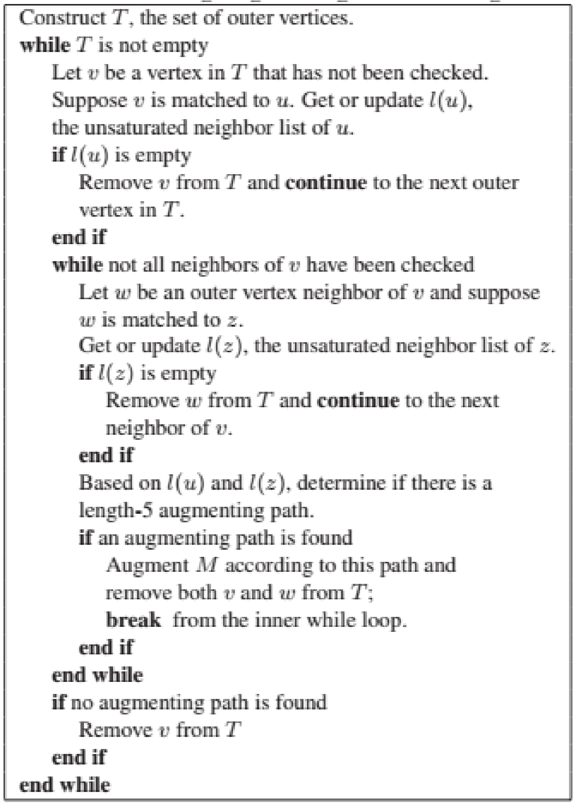
```
Initially, $M = S$ where $S$ is a maximal matching.
for $i = 1$ to $|S|$ do
    Let $(u, v)$ be the $i^{th}$ edge in $S$.
    Check if $u$ and $v$ have distinct unsaturated neighbors.
    if yes
        Let the neighbors of $u$ and $v$ be $x$ and $y$, respectively.
        $M \leftarrow M \cup \{(x, u), (v, y)\} \setminus \{(u, v)\}$.
    end if
end for
```

If there are such vertices, say, u is adjacent tox and v is adjacent to y, there is an M-augmenting path oflength 3 involving (u, v) which is x − u − v − y. We can eliminate this augmenting path and augment M by removing(u, v) from M and adding (u, x) and (v, y) to M. We call(u, x) and (v, y) the new matching edges. The algorithmterminates when all edges in S have been checked this way.

B. Eliminating Augmenting Paths of Length 5

After eliminating augmenting paths of length 3, we searchfor augmenting paths of length 5. We first check all edgesin the current matching to construct a set T. A vertex vis added to set T if v is matched to some vertex u and uis adjacent to at least one unsaturated vertex. We call van "outer vertex" and u an "inner vertex." Note that v canbe both an outer vertex and an inner vertex when v and uare both adjacent to the same unsaturated vertex and arenot adjacent to any other unsaturated vertices. Clearly, to find augmenting paths of length 5 is to find adjacent outervertices. Also note that T can be constructed in O(|E|)time.The algorithm is summarized in Table 2 and works asfollows. We check the vertices in T from the first to the last.When checking vertex v, let u be the inner vertex matchedto v. We first get or update l(u) which is the list of unsaturated neighbors of u: If l(u) has not been established earlier,we search the neighbor list of u to get l(u); otherwise, wecheck the vertex in l(u) (in this case, there can only be onevertex in l(u), for reasons to be seen shortly) and remove itfrom l(u) if it has been matched. After getting l(u), if l(u)is empty, we quit checking v, remove v from T and go onto the next vertex in T. Otherwise, we check the neighborsof v to find an outer vertex.

Table 2. Finding Augmenting Paths of Length 5



```
Construct $T$, the set of outer vertices.
while $T$ is not empty
    Let $v$ be a vertex in $T$ that has not been checked.
    Suppose $v$ is matched to $u$. Get or update $l(u)$,
    the unsaturated neighbor list of $u$.
    if $l(u)$ is empty
        Remove $v$ from $T$ and continue to the next outer
        vertex in $T$.
    end if
    while not all neighbors of $v$ have been checked
        Let $w$ be an outer vertex neighbor of $v$ and suppose
        $w$ is matched to $z$.
        Get or update $l(z)$, the unsaturated neighbor list of $z$.
        if $l(z)$ is empty
            Remove $w$ from $T$ and continue to the next
            neighbor of $v$.
        end if
        Based on $l(u)$ and $l(z)$, determine if there is a
        length-5 augmenting path.
        if an augmenting path is found
            Augment $M$ according to this path and
            remove both $v$ and $w$ from $T$;
            break  from the inner while loop.
        end if
    end while
    if no augmenting path is found
        Remove $v$ from $T$
    end if
end while
```

If an outer vertex w is foundto be adjacent to v, let z be the inner vertex matched to w.We get l(z) which is the unsaturated neighbor list of z inthe same way as for u. If l(z) is empty, we remove w fromT and go on to the next neighbor of v. Otherwise, we checkif there is an augmenting path of length 5 involving (u, v)and (w, z), and note that this can be in constant time. Thisis because (1) if l(z) contains at least 2 vertices, there mustbe such a path; (2) if l(z) contains exactly 1 vertex, thereis such a path if and only if l(u) is different from l(z). Ifan augmenting path is found, we augment M according tothis path and remove both v and w from T; otherwise, wecontinue to check the next outer vertex neighbor of v. If allneighbors of v have been checked and no augmenting pathis found, we remove v from T and continue to the next vertex in T. Now we can see why if an outer vertex is still inT after it has been checked, the unsaturated neighbor listof the inner vertex matched to it must contain exactly onevertex. This is because if it contains more than 1 vertices,an augmenting path must have been found when checkingthis outer vertex and it would have been removed from T.The algorithm terminates when T is empty. Note that thisalgorithm makes sure that it will find an augmenting path oflength 5 involving (u, v) if such a path exists when checkingouter vertex v. Also note that removing an element in a setis equivalent to marking this element which takes constanttime.

IV. PERFORMANCE STUDY

The performance of a wireless network depends on manyfactors, for example, the physical environment, the locations of the wireless nodes, etc., such that the performance ofone network could be different from that of another evenwhen they are using the same devices. In many cases theperformance of the same network may also be changing dueto the occasional movements of the wireless nodes. Thismakes the performance evaluation in general a difficult job.However, we note that the performance gain of adoptingMPT is mainly determined by the probability of two nodesbeing compatible, and this probability should be the samein networks under similar environments and with same devices.

A. Maximum Arrival Rate

The first and the most important question is: After usingMPT, how much faster does the downlink become? This canbe measured by the maximum allowable arrival rate, wherean arrival rate is allowable if it does not cause the bufferof the AP to overflow. More specifically, suppose once theAP has got access to the media, on average it has to waitT seconds to be able to get access to the media again. In the following, for convenience, we refer to T as a time slot.

B. Average Packet Delay

As we have seen, adopting MPT can greatly increase themaximum allowable arrival rate. Note that MPT can alsoreduce the queuing delay of the packets comparing to Single Packet Transmission (SPT).

V. CONCLUSION

We studied the performanceof wireless LAN after enhanced with MPT. We gave analytical bounds for maximum allowable arrival rate whichmeasures the speedup of the downlink and our results showthat the maximum arrival rate increases significantly evenwith a very small compatibility probability. We also usedan approximate analytical model and simulations to studythe average packet delay and our results show that packetdelay can be greatly reduced even with a very small compatibility probability.

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