A scheduling approach for improved Quality of Service in Multi-hop relay based Wireless Cellular Networks

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Abstract: In this paper, we study the effect of multi hop relaying on the throughput of the downstream channel in cellular networks. In particular, we compare the throughput of the multi hop system with that of the conventional cellular system, demonstrating the achievable throughput improvement by the multi hop relaying under transitive transmission considerations. We also propose a hybrid control strategy for the multi hop relaying, in which we advocate the use of both, the direct transmission and the transitive multi hop relaying. Our study shows that most of the throughput gain can be obtained with the use of a transitive relaying scheme. Substantial throughput improvement could be additionally obtained by operating the concurrent relaying transmission in conjunction with the non concurrent transmission. We also argue here that the multi hop relaying technology can be utilized for mitigating unfairness in quality-of-service (QoS), which comes about due to the location-dependent signal quality. Our results show that the multi hop system can provide even more QoS over the cell area. The multi hop cellular network architecture can also be utilized as a self-configuring network mechanism that efficiently accommodates variability of traffic distribution. We have studied the throughput improvement for the uniform, as well as for the non uniform traffic distribution, and we conclude that the use of transitive relaying in cellular networks would be relatively robust to changes in the actual traffic distribution.

Keywords – Quality Of Service, Throughput, Mobile Station, Relay Station, fairness

I. INTRODUCTION

MULTIHOP cellular networks have been proposed as an extension to the conventional single-hop cellular network by combining the fixed cellular infrastructure with the multi hop relaying technology that is usually used in ad hoc networks. Due to the potential of the multi hop relaying to enhance coverage, capacity and flexibility, the multi hop cellular networks have been attracting considerable attention. This approach of augmenting cellular communication with multi hop relaying was also used in the standardization effort to include the multi hop relaying into the third-generation (3G) mobile communication systems [1].

The primary advantage of the multi hop relaying comes from the reduction in the overall path loss between a base station (BS) and a mobile station (MS) [2]. However, the penalty for employing multi hop relaying is in the need for additional radio channels. Another benefit of the multi hop relaying is the path diversity gain that can be achieved by selecting the most favorable multi hop path in the shadowed environment. This diversity gain can increase with the number of MSs, as then the number of potentially relaying candidate’s increases and the possibility of finding a relay with lower path loss increases as well. In addition, system capacity can additionally increase by allowing concurrency among the multi hop transmissions. However, such concurrency also increases the interference. So, the overall effect is not immediately clear.
As we saw above, the performance of the multihop cellular networks is governed by various tradeoffs. Thus, to benefit from the multihop relaying, the various tradeoffs should be comprehensively studied. However, the exploration of such tradeoffs in the literature is very limited. In particular, the analysis of the tradeoff caused by the concurrent transmissions between the interference and the channel reuse efficiency is of vital importance.

Toumpis and Goldsmith [3] showed that the concurrent transmission can enhance the system capacity of the multihop cellular networks. However, their results were obtained for a single cell system and for just two cases of network topology, i.e., a linear topology and a single realization of a random topology. Hence, those results are insufficient to demonstrate, in general, the concurrency tradeoff. Moreover, several studies reported that it is not easy to enhance the capacity of code-division multiple-access (CDMA) systems by the use of the multihop relaying [5]–[9]. This is mainly due to the interference increase resulting from the concurrent transmissions. Such interference might be the most significant factor limiting the network capacity. Hence, the impact of the concurrent transmission should be carefully investigated. The multihop relaying technology can provide a significant flexibility in the design and the operation of the cellular network.

In the multihop cellular networks, MS can choose to utilize the multihop relaying instead of the single-hop direct transmission. Such a hybrid operation can be exploited for various purposes; one of which is to mitigate the unfairness in the quality of service (QoS) among the users. In cellular networks, there is a tradeoff problem between system throughput and QoS fairness [4]. Since the received signal quality depends on the user location, it is not easy to provide an even QoS over the whole cell service area and to maximize the system throughput at the same time. On the other hand, the use of multihop relaying, instead of a direct link, can improve the QoS of the users with poor direct link who are located near the cell boundary or in a deep shadowed region. Therefore, the fairness, as well as system throughput in the cellular network can be improved through the use of the multihop relaying.

Another application exploiting the flexibility of the multihop relaying technology is to mitigate the inefficiency due to the temporal changes in traffic demand in cellular networks. To optimize the performance of a cellular system, finding the optimum positions of the cell sites is a crucial problem in interference limited systems, such as the CDMA type systems. However, due to the ever-changing traffic demand patterns, optimal placement of cell site is a difficult problem. Even if the traffic distribution could be estimated, it would still be difficult to optimally plan the radio network, as the fixed cell sites cannot be relocated whenever the traffic distribution changes. Hence, there is a need for a self-configuring network, which would be capable of automatically coping with the changes in traffic distribution.

In the multihop cellular network, the alternative selection of the multihop path can allow flexible design of the cell site, which is particularly important in the case of non uniform traffic distribution. Thus, the multihop cellular network architecture can be utilized as a self-configuring network mechanism that can efficiently accommodate the spatial and temporal variability of traffic patterns.

Although the multihop relaying technology has been proposed as one of the key technologies for the self-configuring cellular networks [10], [11], there have been only few numerical results clarifying how the self-configuring feature achieved through the multihop relaying can improve the system capacity for non uniformly distributed traffic case. Though Wu et al. [12] evaluated the capacity of the multihop system with non uniform traffic, such that when the traffic between adjacent cells is unbalanced, that paper focused only on the channel borrowing between adjacent cells through multihop relaying. Moreover, some features of the multihop relaying, such as path-loss reduction and path diversity, were not considered in their analysis. Hence, their results may not be able to fully explain the behavior of the self-configuring capability of multihop relaying itself.

The problem studied here is to design a scheduling algorithm for multi-hop relay wireless cellular networks, so that it can properly arrange the concurrent
transmission scenarios for multi-hop relay links, and the overall network throughput can be improved.

![Figure 1. Cellular Network with Transitive relay topology](image)

II. RELATED WORK

The study of combining relay networks with cellular networks has been going on for quite a while. When designing a relay network inside the cellular network, there are many optional factors, such as whether or not the relay network adopts the ad hoc implementation, and whether or not the RS should use the same cellular spectrum to relay traffic, referred to as in-band relay. However as in [13], the ad hoc implementation has some drawbacks. The first drawback is that ad hoc routing needs each node in the relay network to participate in the route finding process that involves broadcasting, feedback, and forwarding of routing message, and this participation requires significant modifications of the signaling protocols of wireless cellular networks. These significant modifications in the signaling protocols of the BS and the MS make the current cellular network operator reluctant to deploy relay network. Second, the algorithm for finding ad hoc routing occupies a certain amount of bandwidth from each mobile node, and more bandwidth consumption is anticipated in order to keep the routing table up to date, since nodes are mobile in the network. Third, the frequent changes in the routing table reduce the reliability of the data delivery and affect the total network throughput. Therefore, the ad hoc implementation is unattractive to the network operator in industry, since the BS, the RS, and the MS all have to adjust to the architecture changes of the cellular network, and the extra signaling overhead and bandwidth consumption incurred for each MS is significant. Observing the drawbacks of the ad hoc implementation of a relay network, we prefer an approach that involves minimum network architecture changes and still can enjoy the advantages of multi-hop concurrent transmissions. A desirable solution should be able to incorporate a relay network into the current cellular network with insignificant architecture modification and small implementation overhead, and the new network architecture is still controllable from the point view of the network operator.

Other choices include whether or not the MS can serve as the RS and whether or not the scheduling algorithm for concurrent transmissions should be centralized. How to wisely choose among these options to form an adaptive relay network is a challenging task. On such attempt is the development of a WiMAX draft standard, 802.16j, which is a revision of WiMAX with the intent of incorporating relay network into WiMAX network. This 802.16j draft standard has the following characteristics. The RS in 802.16j is for relay traffic only, and the scheduling algorithm is centralized and run in the BS. The RS uses the same spectrum as the BS and the MS, and no ad hoc routing is allowed in the relay paths. The approach in 802.16j allows WiMAX network to incorporate relay network without sacrificing WiMAX network architecture, and the WiMAX BS is still able to manage the RS.

In 802.16j, BS runs the scheduling algorithm and maintains full control over RS. While RS is for traffic relay only and uses the same spectrum as BS and MS. Each RS aggregates the traffic from the nearby MS. A linear programming model is then developed to calculate the minimum time to transmit a fixed data load from the BS to every RS over possible multiple hops. Since the transmission time is minimized for the fixed data load, throughput is maximized. However, it does not taken into consideration the varying queue size of each relay station, neither does it apply the frame boundary of cellular network into transmission. Since
wireless cellular networks are predominantly frame-based, it is non-trivial to study the scheduling algorithm for multi-hop relay network under frame-based assumptions.

III. NETWORK ARCHITECTURE & CHALLENGES

In a cellular network with frame-based transmissions, base station connects to relay station and/or mobile station, and each relay station can connect further to other relay station and/or mobile station. Relay station only forwards traffic to/from mobile station and generates no traffic of its own. Relay station is transparent to mobile station, and mobile station does not involve in routing packets for other mobile station. Base station, relay station, and mobile station all share the same spectrum, thus no additional hardware such as a second physical interface is needed. Base station needs to gather the downlink real time queue size of its associated relay station and this queue information is sent to base station using uplink bandwidth. The resulting signaling change due to uplink queue status is insignificant, and the corresponding uplink bandwidth consumption is negligible. After gathering relay station queue information, base station run the scheduling algorithm to obtain the downlink scheduling results and broadcasts the results to relay station and mobile station.

As the input for the scheduling algorithm, concurrent transmission scenarios need to be determined in an efficient way. When adding a link candidate into a concurrent transmission scenario, it must be guaranteed that adding this link will not decrease the total throughput of this scenario. However, it is not practical to traverse all possible links searching for concurrent scenarios due to the non-linear growth of links with respect to number of MS and RS.

Scheduling in cellular relay networks is challenging as in [18], [19]. First, as the input for the scheduling algorithm, concurrent transmission scenarios need to be determined in an efficient way. When adding a link candidate into a concurrent transmission scenario, it must be guaranteed that adding this link will not decrease the total throughput of this scenario. However, it is not practical to traverse all possible links searching for concurrent scenarios due to the non-linear growth of links with respect to number of MS and RS. The Second challenge is due to fact that wireless cellular networks are predominantly frame-based, and the corresponding scheduling algorithm must take this factor into consideration. In each frame, different concurrent scenarios must share this frame duration. Thus arises the issue of fair allocation of time resources among various MS who share one frame, while still achieving the goal of achieving max network throughput. The third challenge is to let the scheduling algorithm adjust to the real time queue size change in RS.

IV. SCHEDULING ALGORITHM UNDER LINEAR PROGRAMMING

A linear programming model to implement the scheduling algorithm for wireless cellular multi hop relay network is discussed as in [20]. A cellular relay network which has M mobile Stations and R relay stations under the control of one BS. The downlink frame duration is T seconds, and the frames are indexed by t in the time domain. The dynamic queue information of each RS is sent to BS in the uplink frame that precedes each downlink frame, and based on these queue information, BS makes the scheduling decision for the downlink frame.

OBJECT FUNCTION:

Maximize \( \sum_{m} a_{m}(t) \)

INPUT VARIABLES:

1: MS index m;
2: frame index t;
3: frame duration T;
4: RS node i’s queue status \( Q_{i,m}(t) \);
5: a set of concurrent transmission scenarios \( S_{k} \), \( 1 \leq k \leq K \);
6: power used from node i to j, \( P_{ij} \);
7: distance between node i to j, \( d_{ij} \);

OUTPUT VARIABLES:

1: \( x_{ij,m}(k, t) \), scheduled packets transmitted from node i to j in \( S_{k} \) at frame t, which are destined for MS node m;
2: \( T_{k}(t) \), scheduled time portion for scenario \( S_{k} \)
A set of all links in a concurrent transmission scenario can transmit at the same time, i.e., no two links in a concurrent transmission scenario can share the same transmitter or receiver. Let \( x_{ij}^m(k, t) \) denote the number of bits transferred from node I to j destined for MS node m at frame t, from node i to node j. We name node i the upstream node of node j, and node j the downstream node of node i. Each RS node i has a queue for every MS node m.

Let \( Q_{im}^m(t) \) denote the size of this queue at the beginning of the downlink frame t. Since MS consumes only the packets destined for itself and MS does not relay packet, there is no need for MS to maintain any queue. Packets arriving in MS node m at frame t are the sum of packets sent by its neighboring nodes over all scheduled transmission scenarios at frame t.

V. PROPOSED METHOD: SCHEDULING UNDER TRANSITIVE RELATION CONSIDERATIONS

Transitive relation between BS and RS is considered and this constraint influence the actual delay measured at RS that connected directly to the BS which is not addressed in the previous work.

The model detects all concurrent transmissions, and responds by invoking scheduling activities as appropriate. The relay station queues that are transitively connected to BS also be considered to conclude the Queue capacity of the relay station that relies in middle between BS and transitive relay station.

The number of links grows non-linearly with the number of nodes in the network; it is impractical to use an exhaustive algorithm to search for all possible scenarios. We use a linear programming model stated to calculate the transmission schedules for all concurrent transmission scenarios, aiming at maximizing the throughput in each frame. Here we consider the transmission schedules those influenced by the transitive relations between BS and RS.

Under transitive condition the count of relay stations \( r \); RS node i’s queue status under transitivity is given as

\[
\sum_{r=1}^{tc} Q_{ir}^m(t)
\]

This is applied in the Scheduling algorithm under Linear Programming which is mentioned in Chapter-4.

CONSTRAINTS:

1. \( S_{sm} = \sum_{s,k=1}^{K} X_{sm}(k,t) \) & \( a_m(t) = \sum_{k=1}^{K} S_{sm}(k) \)
   Where s is MS node m’s upstream node’ index;

2. \( \sum_{r=1}^{tc} \sum_{k=1,s}^{K} x_{si}^m(k,t) + \sum_{w,k=1}^{K} x_{iw}^m(k,t) + \sum_{r=1}^{tc} Q_{im}^m(t+1) \)
   \( r = 1 \)
   \( k = 1,s \)
   \( w, k = 1 \)
   \( r = 1 \)
   Where ‘i’ is RS index and r is transitive RS index and tc is transitively connected relay station count. ‘s’ and ‘w’ stands for node i’s upstream and downstream node, respectively;

3. \( \sum_{k=1,s}^{K} x_{ij}^m(k,t) \leq W_{ij}(k,t) \star T_k(t) \)

4. \( W_{ij}(k,t) = \theta \log_2 (1 + \frac{P_{ij}/d_{ij}^{\alpha}}{N_0 + \sum_{(x,y) \in Sk,(x,y) \neq (i,j)} P_{ij}/d_{ij}^{\alpha}}) \)
   where \( \alpha \) is the path loss exponent, and \( N_0 \) is noise power;

5. \( \sum_{k=1}^{K} T_k(t) = T \)

6. \( \sum_{r=1}^{tc} Q_{ir}^m(t) \)

The characteristics of the proposed scheduling algorithm are highlighted by the following constraints.
Constraint 1: Derives the throughput for Mobile Station node in frame, revealing the concurrent transmission nature of the multi hop cellular networks.

Constraint 2: Indicates the queue awareness of the proposed scheduling algorithm by monitoring the dynamic RS queue status, and this queue awareness is not addressed by the related work.

Constraint 3: The capacity constraint of a link in scenario Sk.

Constraint 4: Applies Shannon’s Theorem to calculate the upper bound of link data rate with consideration of the interference caused by concurrent transmissions.

Constraint 5: States the time constraint of all concurrent scenarios in a frame, signifying the frame-based feature of this approach.

Constraint 6: Transitive relation between BS and RS will be considered and this constraint influence the actual delay measured at RS that connected directly to the BS which is not addressed in the previous work.

**Defining and Deriving the Greedy Approach:**

In this Greedy Approach we apply the back pressure flow control mechanism. This mechanism states that in order to maximize the end-to-end throughput in multi hop wireless network, the selected concurrent transmissions must be able to maximize the object function. We use a greedy algorithm to derive a set of concurrent transmission scenarios, with the back pressure flow control mechanism incorporated into the greedy algorithm.

This is defined as: 

\[ F(s) = \sum (i,j) \in S \frac{w_{ij}}{R_{ij}} \]

**Process flow:**

![Figure 3. Backpressure flow mechanism](image)

**VI RESULTS**

The Queue aware scheduling under transitive connection considerations has been implemented using mxml and action script. The implementation is based on multi-hop relay based wireless cellular network routing functions that are added. In additional to building QoS routes, the protocol also establish a best schedule strategy when it learns such requirement. The best-effort scheduling is used to increase the throughput. A distributed protocol which dynamically generates and updates transmission schedules among the nodes has been used. Assumed transmission rate is 1 Mbps. The model detects all concurrent transmissions, and responds by invoking scheduling activities as appropriate. The relay station queues that are transitively connected to BS also be considered to conclude the Queue capacity of the relay station that relies in middle between BS and transitive relay station. We apply greedy search technique to identify concurrent relations of the simulation. And finally conclude the scheduling strategy using the linear program technique proposed. These greedy search and linear approach we implemented using action script. The linear approach considers the 6 different constraints explored above.
TABLE I. Average throughput per node (Mbits/frame)

<table>
<thead>
<tr>
<th></th>
<th>With Transitivity Constraint</th>
<th>W/O Transitivity Constraint</th>
<th>Direct Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput</td>
<td>0.5 1 1.5 2 2.5 3 3.5</td>
<td>0.5 1 1.5 2 2.5 2.9 3.1</td>
<td>0.5 1 1.5 2 2.5 3.5 2.5</td>
</tr>
</tbody>
</table>

Figure 4. Throughput Comparison report

VII CONCLUSION AND FUTURE WORK

We have presented a Transitive relation aware scheduling algorithm for multi-hop relay wireless cellular networks. In the scheduling algorithm, first a set of concurrent transmission scenarios is derived and then it is used as input for a linear programming model that determines the transmission schedules for the multi-hop relay network. The linear programming model aims at maximizing the overall throughput of the all the mobile stations, while taking into consideration the frame-based nature of cellular network and the dynamic queue change in the relay stations. The features of frame-based and queue-awareness of the scheduling algorithm are the unique contributions that have not been addressed by previous work. Simulations measure performance metrics such as throughput and fairness of the proposed scheduling algorithm. Two other scheduling algorithms are compared with our approach via simulations. One is scheduling for direct transmission only, and the other is scheduling without buffer in the relay nodes. The effectiveness of our approach is validated by the simulation results. There are a number of directions we are currently exploring. By taking the actual multihop relay wireless cellular network scenario, we are extending the approach presented in this paper to obtain better performance for all traffic flows. Using the insights obtained in this paper, we are also studying different scheduling mechanisms for different traffic flows. Through this study, we hope to obtain useful provisioning rules for providing predictable Internet QoS.

References:


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