Optimal Frequency of Walsh Mask Broadcast for Forward High-Speed Wireless Packet Data Channels

Rath Vannithamby, Patrick Hosein, Srinivasan Balasubramanian
Ericsson Wireless Communications, Inc.
5012 Wateridge Vista Dr., San Diego, CA 92121
{rath.vannithamby, patrick.hosein, sribalasubramanian}@ericsson.com

Abstract—The 1xEV-DV Third Generation wireless network system is able to simultaneously support traditional code division multiplexed voice and circuit-switched data channels in addition to one or two time shared high speed packet data channels. In practice, voice calls will be provided with higher priority than data calls. Therefore, radio resources (e.g., power and Walsh codes) will be first given to voice connections and any unused resources will be dynamically assigned to the high speed packet data channel. Because of Walsh code fragmentation, it may be possible that Walsh codes not being used for voice and circuit-switched data connections cannot be used by the packet data channel. In order to make use of such codes, the Walsh code mask must be broadcast in the sector. Such a broadcast results in increased sector throughput due to the additional Walsh codes available to the forward packet data channel (F-PDCH) but it also requires forward link resources which reduces throughput. We determine the broadcast frequency that optimizes this tradeoff.

I. INTRODUCTION

IS-2000 Revisions C and D [1], [2] were developed to satisfy the push for high-speed wireless data services at rates significantly beyond those defined in current wireless cellular systems on the forward and reverse links respectively. Revision C and D, which are backward compatible with previous revisions [3], are also referred to as 1xEV-DV (1x radio transmission technology Evolution for high-speed integrated Data and Voice). The push for higher data rates is motivated by the growing demand for wireless data services such as mobile Internet, video-streaming and multimedia among others. In this paper, we focus on the forward link of a 1xEV-DV network and address the issue of Walsh code allocation.

Prior to 1xEV-DV, Walsh code resources were solely dedicated to individual users over the forward link. In this approach, dedicated channels are power controlled to compensate for fading, and assigned a set of channelization codes referred to as "Walsh codes" for a relatively long period of time (on the order of seconds or minutes). Allocation of resources in this fashion is characteristic of circuit switching. Circuit switching, however, is inefficient for bursty data traffic as typically seen over the Internet. The loss due to explicit Walsh code assignment is well known because when there is no data to be transmitted, the already dedicated resource is wasted. For the loss due to power controlling the dedicated channel, the radio condition can change rapidly (on the order of ms), the extended allocation of resources to a MS (eg. for a second or longer) can result in large swings of power requirements and, hence, poor resource utilization.

There are three major new resource allocation concepts introduced in the 1xEV-DV forward link, namely channel quality information feedback, fast scale TDMA-sharing of F-PDCH and the utilization of leftover radio resources. If multiple Mobile Stations (MS) were to share the Base Station (BS) resources with time-division-multiplexing, then resource wastage can be minimized. If forward link channel quality information were available at the BS, then resources could be optimally scheduled to improve spectral efficiency. Resources can be allocated to a MS (experiencing fading) when its channel quality is good. This approach not only avoids wasting resources, but also improves the spectral efficiency by serving MSs with rates higher than those without this approach. The resources are allocated for a brief period of time and can be re-allocated to different MSs quickly, up to once every 1.25 ms. The concept of sharing Walsh codes for high-speed data transmission is not novel. It has been used previously for the shared forward supplemental channel (SCH). However, in that case, a Walsh code is dedicated to a single MS for a relatively longer period of time, on the order of a few 100 msecs.

In principle, resources should always be utilized (when there is a demand for them). However, in current systems, leftover resources that cannot be utilized may exist. The amount varies with time, and it depends on the number of dedicated Walsh code channels and power allocated per channel. 1x EV-DV makes use of these leftover resources for the shared packet data channel, maximizing the utilization of all available resources. The use of a shared packet data channel in place of multiple dedicated data channels allows for accommodating variability in the data traffic fully using all resources all the time. The dedicated approach would require power margins and would not be able to accommodate short-term changes in resources due to the departure, arrivals and variability in the voice service.

In this paper, we discuss the challenges in assigning Walsh codes for various channel types such as voice and circuit-switched data channels, and efficiently utilizing the leftover Walsh codes for the F-PDCH. We also explain the tradeoff between the utilization efficiency of the leftover Walsh codes and the associated overhead in sending Walsh mask broadcast.
Finally, we analyze the tradeoff and give recommendations on the criteria for sending Walsh mask broadcast to increase the Walsh code utilization efficiency for 1xEV-DV system.

II. WALSH CODE MANAGEMENT

The major requirement in 1xEV-DV is to be backward compatible with previous revisions, i.e., all conventional voice and data channels need to be supported, and the F-PDCH should be able to use the leftover Walsh codes and power. F-PDCH can use up to 28 length-32 Walsh codes. The rest of the Walsh codes are needed for controlling and signaling purposes, and can also be used for conventional voice/data channels.

Prior to 1xEV-DV high data rates up to 614.4 kbps were achieved via the forward supplemental channel (F-SCH) by assigning different length Walsh code. For example using rate set 1 (RS1), Length 128, Length-64, length-32, length-16, length-8 and length-4 Walsh codes are used to achieve rates of 9.6, 19.2, 38.4, 76.8, 153.6 and 307.2 kbps respectively [3]. This approach is called variable spreading gain CDMA (VSG-CDMA) in the literature. Note that a rate of 614.4 kbps is made possible by assigning two length-4 Walsh codes. Alternatively, in 1x-EV-DV, different data rates are achieved by using multiples, not necessarily contiguous, of length-32 Walsh codes. This approach is called multi-code CDMA (MC-CDMA). The capacity of VSG-CDMA and MC-CDMA are derived in [4], [5].

Mobiles knowing the leftover length-32 Walsh codes, can combine them for the F-PDCH reception. Theoretically, the Walsh codes used for F-PDCH can change every 1.25 ms as the conventional voice/data channels occupy or leave Walsh codes. The random nature of the arrival/departure process will create fragmentation in the Walsh space. For circuit-switched channels, an age-based algorithm can be used for efficient Walsh space packing, nevertheless, fragmentation in the Walsh space cannot be avoided. Hence, the BS sends the Walsh space availability for the packet data channel in a broadcast message in order to dynamically change the Walsh code usage for the F-PDCH.

Table I shows the format of the Walsh mask broadcast message that is sent on the forward packet data control channel (F-PDCCH). It consists of 21 bits. The first 8 bits is an identifier which specifies what message it is (all zeros mean it is a broadcast message and the rest of the 13 bits specify the Walsh space availability. Table II shows the format of the F-PDCCH message that is sent in parallel with the data that carries all the necessary information (mobile station identifier, hybrid-ARQ related parameters and the last Walsh code index) for the intended mobile station to decode the data.

In terms of Walsh space utilization, it will make sense to send a broadcast with 28-bit bitmap to represent which of the length-32 Walsh codes are available for packet data channel. However, there is an overhead associated with this broadcast. In order to balance out the tradeoff between Walsh space utilization and broadcast overhead, it was decided in the standards [1] to send the availability information of the length-16 Walsh codes. Hence, a 14-bit bitmap is needed to represent 14 of the length-16 Walsh codes. However, a 13-bit bitmap is chosen in the standards [1] for the broadcast since it matches with the other F-PDCCH overhead messages (i.e., message size 21 bits) and the fact that the 14th bit represents an obvious case. Note that there are four different Walsh code tables that can be used for the F-PDCCH [1] based on the Walsh codes used for various overhead channels such as paging channel (F-PCH).

The base station notifies the mobile station of the Walsh space that is to be used for the F-PDCH using the Walsh

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**TABLE I**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAC_ID</td>
<td>8 bits</td>
</tr>
<tr>
<td>Walsh mask bitmap</td>
<td>13 bits</td>
</tr>
</tbody>
</table>

**TABLE II**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAC_ID</td>
<td>8 bits</td>
</tr>
<tr>
<td>sub packet identifier (SP_ID)</td>
<td>2 bits</td>
</tr>
<tr>
<td>ARQ channel identifier (AC_ID)</td>
<td>2 bits</td>
</tr>
<tr>
<td>ARQ channel identifier sequence number (AI_SN)</td>
<td>1 bit</td>
</tr>
<tr>
<td>Last Walsh code index (LWCI)</td>
<td>5 bits</td>
</tr>
</tbody>
</table>

**Fig. 1. Sample Walsh Mask Assignment**
mask broadcast and the LWCI field (see Table II). The latter specifies the last length-32 Walsh code index that should be included for the F-PDCH reception. The Walsh mask broadcast is generally chosen to be a slow process due to it’s overhead and the update on the LWCI is a fast process since every F-PDCH transmission carries this field in the associated F-PDCCH control message.

Figure 1 shows an example of how the Walsh mask broadcast can be used to identify what are the Walsh codes currently used for the voice and the circuit-switched data, and what are the length-32 Walsh codes that should be combined for the associated F-PDCH reception. It is generally accepted that voice calls will be allocated from the bottom, and the circuit-switched data (via F-SCH) will be allocated from the top of the Walsh code tree. In Figure 1, Walsh mask broadcast (in left) specifies that length-32 Walsh codes 0-7, 14-15, 21-27 are currently in use for voice and circuit-switched data, hence shall not be used to decode the F-PDCH data. Note that even though only length-32 Walsh code 15 is in use but 14 is available, the Walsh mask broadcast needs to mask out both 14 and 15. Moreover, Length-32 Walsh code index 15 illustrates how badly the Walsh code tree can be fragmented due to the nature of the arrival/departure of the voice calls though the voice calls are assigned the Walsh codes from the bottom of the tree. Length-32 Walsh code index 21 is in use for voice, but 20 is available. Hence, it is possible to take advantage of LWCI field in order to make use of the unused Walsh code index 20. In summary, the mobile station knows from the Walsh mask broadcast and the LWCI field that it needs to include the length-32 Walsh codes 8-13 and 16-20 for the associated F-PDCH reception without any ambiguity.

Several triggers can be used to update the Walsh mask update at the mobile stations of which the key ones are considered below: (1) Periodic - to sync up with all the mobile stations and to make sure all the mobile stations have the appropriate Walsh mask; i.e., to correct any potential errors, (2) New arrivals - when new mobile stations come to a sector either from new PDCH assignment or due to cell switching, the current Walsh mask in use for the sector needs to be communicated to these mobile stations, (3) Walsh code availability changes - when the Walsh codes are taken or freed up by F-SCH users, Walsh mask broadcast needs to be sent. There is no need to send the Walsh mask broadcast when the currently available Walsh codes are taken by voice calls since LWCI can reflect this change. However, when Walsh codes are freed up by the voice calls, Walsh mask broadcast can be sent to optimize the Walsh code utilization. This optimization mechanism is analyzed in detail in the next section.

III. ANALYTIC MODEL

Our objective is to determine the Walsh mask broadcast frequency that maximizes the F-PDCH throughput. When a user departs, the Walsh code that was used may be rendered unavailable until Walsh code reallocations are made. Let $\lambda$ denote the average rate of creation of these holes (i.e., a Walsh code that is unusable by the F-PDCH). The codes remain unavailable for some period of time before becoming available again. Denote the average value of this holding time by $\kappa$. Note that these are Walsh codes that may be available for new voice connections but cannot be used for the F-PDCH until a Walsh mask broadcast is performed.

In steady state the average number of unavailable codes is therefore given by $U = \lambda \kappa$. In the below discussion we assume this to be an integer otherwise the nearest integer is used. In steady state and with no Walsh code broadcasts assume that an average of $N$ Walsh codes are used for the F-PDCH. Therefore if, in steady state, a broadcast is made then an average of $N + U$ codes become available for the F-PDCH and this number gradually drops down to $N$ unless another broadcast is made (see Figure 2).

Let $R(N)$ denote the sector throughput (note that we assume that the power available to the F-PDCH during this control period is constant) when $N$ Walsh codes are available to the F-PDCH. If the unavailable codes were to be made available to the F-PDCH (by a broadcast) then the F-PDCH throughput can be increased to $R(N + U)$.

Suppose that Walsh code broadcasts are used to reduce the average number of unavailable codes. First note that it is optimal to make these broadcasts at time instants when a Walsh code becomes unavailable. Assume instead that a Broadcast is made at some time $t$ and that the last unavailable code was created at time $t - \varepsilon$. Had the broadcast been made instead at time $t - \varepsilon$ then a larger throughput would have been experienced during the period $[t - \varepsilon, t]$ and hence the system performance can be improved contradicting our assumption that optimal broadcasts were being made.

Given the above, we must make broadcast decisions whenever a Walsh code becomes unavailable. For simplicity, and since we plan to change the broadcast frequency slowly, we will assume that broadcasts are made every $m$th occurrence of a Walsh code becoming unavailable. $m = 1$ means that
a broadcast is made every time that a Walsh code becomes unavailable. In this case the average number of unavailable Walsh codes becomes 0 and the Walsh code broadcast rate becomes \( \lambda \). Naturally there is a tradeoff between the gain in throughput with increased broadcast rate and the increase in broadcast overhead. The problem objective is the determination of \( m \) such that the overall gain \( G(m) \) is maximized.

Let us first determine the average increase in throughput as a function of \( m \). Consider the case in which \( m \leq U \). Therefore a broadcast is made before the number of unavailable Walsh codes reaches the steady state value. The average throughput as a function of \( m \) is given by

\[
\bar{R}(m) = \frac{1}{m} \sum_{i=1}^{m} R(N + U - i + 1)
\]

If \( m > U \) then we assume that once the number of unavailable codes reaches \( U \) then it remains at that value. Therefore in this case the average throughput becomes

\[
\bar{R}(m) = \frac{1}{m} \left( (m - U)R(N) + \sum_{i=1}^{U} R(N + U - i + 1) \right)
\]

Assume that each broadcast requires a single F-PDCH slot and denote a slot size by \( \tau \). The broadcast is performed just before the unavailable codes can be used and hence the potential throughput at that point in time is given by

\[
B(m) = R(\max\{N, N + U - m + 1\}).
\]

The number of potential transmitted bits is given by \( B(m)\tau \). The time between these broadcasts is given by \( m/\lambda \) and hence the loss in sector throughput is given by \( B(m)\lambda\tau/m \).

The throughput gain as a function of \( m \), \( G(m) \) is the difference between the gain (from the the increased Walsh codes) and the throughput loss (due to the slot taken by the broadcast). This gain can therefore be written as

\[
G(m) = \bar{R}(m) - R(N) - \frac{B(m)\lambda\tau}{m}
\]

and the optimization problem is the determination of the decision variable \( m \) that maximizes this gain.

For the case \( m = 1 \) we have

\[
G(1) = R(N + U)(1 - \lambda\tau) - R(N).
\]

Next note that \( \lambda \) is the frequency of the hole creation and the duration between these hole creations is on the order of hundreds of milliseconds. \( \tau \) however is on the order of a few milliseconds. Therefore \( \lambda\tau \ll 1 \) and since \( R(N + U) > R(N) \) then for sufficiently large \( U \) we will have \( G(1) > 0 \). On the other hand, for sufficiently small \( U \) we have \( G(1) < 0 \). Also note that if multiple slots are used for the broadcast then we can take this into account by increasing \( \tau \). Next note that as \( m \) goes to infinity \( \bar{R}(m) \) approaches \( R(N) \) from above while \( B(m)/m \) approaches zero and hence \( G(m) \) goes to zero.

IV. ILLUSTRATIVE EXAMPLE

In this section we present a simple illustrative example (not a realistic one). Assume that the rate is linearly proportional to the number of Walsh codes, \( R(N) = \alpha N \). Consider the case \( U = 1 \), then \( \bar{R}(1) = \alpha(N + 1) \), \( R(N) = \alpha N \) and \( B(1) = N + 1 \). There we have \( G(1) = \alpha(1 - \lambda\tau(N + 1)) \). For \( m > 1 \) we have, \( \bar{R}(m) = \alpha(N + 1/m) \), \( b(m) = \alpha N \) and hence \( G(m) = (1 - N\lambda\tau)/m \). Therefore \( G(m) \) tends to zero as \( m \) tends to infinity. If \( G(1) < 0 \) then the optimal value of \( m \) is infinity (i.e., never broadcast). If \( G(1) > 0 \) and \( G(1) > G(2) \) then the optimal value is 1 but if \( G(2) > G(1) \) then the optimal value is 2. Typically \( N\lambda\tau \ll 1 \) and hence \( m = 1 \) would be optimal.

V. CONCLUSIONS

We considered the problem of determining the frequency of Walsh mask broadcasts that maximizes the forward link sector throughput for the 1xEV-DV standard. As the broadcast frequency is increased, the average number of Walsh codes available to the F-PDCH increases resulting in increased throughput. However, each broadcast requires a time slot that is lost to user traffic. Therefore there exists some optimal frequency that optimizes this tradeoff between increased throughput and “wasted” time slots. We formulated a simple model for this problem and showed that for typical scenarios it is best to broadcast the Walsh mask each time a Walsh code hole is created. Essentially, the overhead in performing the broadcast tends to be small compared to the gains in sector throughput due to more available Walsh codes. However, we wish to emphasize that a detailed simulation is required to determine the optimal value of \( m \). The intent of this paper was to show that there is in fact an optimal point and that resources can be more efficiently utilized by operating at that point.

Since there are so many unknowns in a real system we suggest that the broadcast frequency be dynamically determined based on system measurements. In other words, the throughput increase that results from an increase in the available Walsh codes should be monitored. Also the throughput that is lost to the broadcast slot should also be monitored. These can then be compared to determine whether the broadcast frequency should be increased or decreased.

REFERENCES


