A New Channel Allocation Scheme for Vehicle Communication Networks

Jing Xu, Wei Li, Zan Ma, and Shuo Zhang

What is this paper about?

Smart roads provide vehicles with updates on traffic, safety warnings and weather conditions. However, being centralized systems, they can suffer from issues such as overloading and single points of failure.

This paper proposes a distributed peer-to-peer (car-to-car) communication scheme that ensures:

- Crucial and lightweight information (e.g. car accidents, hazardous weather phenomena) travels on dedicated, interference-free primary channels;
- High-demand information (e.g. infotainment services) is transmitted on secondary channels, dynamically assigned based on each vehicle's needs.

The Model

Model each car as a circle given by its transmission range and build a (dynamic) intersection graph.

Let's consider the generic node u. As in a labeling problem,

- Any node at distance 1 is a first neighbour
- Any node at distance 2 is a second neighbour

that it has been received by sending ACK from node v to u. $N_1(u)$ denotes nodes which are one hop away from node u, and $N_2(u)$ denotes nodes which are two hops from node u, it is obvious that $u \notin N_1(u)$, $u \notin N_2(u)$. In this paper

We put them together to form the interference set N(u) for node u.

 Bandwidth is divided in K channels, and we assume interference may occur only if two different nodes in a neighborhood use the same channel.

In protocol interference model, $\mathcal{N}(u)$ represents the nodes within two hops away from u, then $\mathcal{N}(u) = N_2(u)$. So it will generate conflicts and interferences if nodes



- Primary channels are found by some raw approximation of L(1, 1).
- Secondary channels are then assigned by a greedy algorithm.

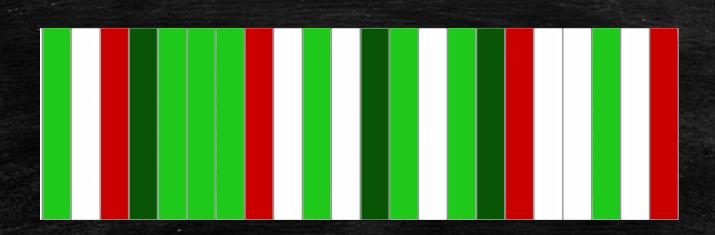
- Primary channels are found by some raw approximation of L(1, 1).
- Secondary channels are then assigned by a greedy algorithm.

- Primary channels are found by some raw approximation of L(1, 1).
- Secondary channels are then assigned by a greedy algorithm.

- Primary channels are found by some raw approximation of L(1, 1).
- Secondary channels are then assigned by a greedy algorithm.

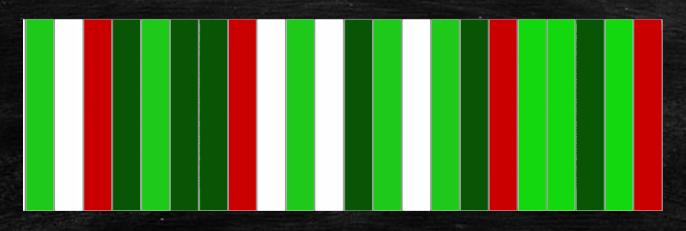
- Primary channels are found by some raw approximation of L(1, 1).
- Secondary channels are then assigned by a greedy algorithm.

- Primary channels are found by some raw approximation of L(1, 1)
- Secondary channels are then assigned by a greedy algorithm.



A single secondary channel may be chosen by more than one node...

- Primary channels are found by some raw approximation of L(1, 1).
- Secondary channels are then assigned by a greedy algorithm.



... while some others may remain unused.

- Primary channels are found by some raw approximation of L(1, 1).
- Secondary channels are then assigned by a greedy algorithm.

If a secondary channel is chosen by more than one node, we perform

Frequency Division Multiplexing (OFDMA)

on that channel, furtherly dividing it into sub-channels.

Tools for choosing the Primary Channels (I)

- Primary channels are found by some raw approximation of L(1, 1).

Suppose to have a K-bit long vector. We have 2^K possible words w_i such that if we define the boolean sum as a bitwise OR operation we have that

- BooleanSum (w_i, w_j) is still a word;
- It may happen that BooleanSum $(w_i, w_j) = w_i$. We say w_i covers w_j .

Tools for choosing the Primary Channels (II)

Given a set W of binary strings of length K, the goal of a Superimposed Code (SC) is to provide a code (i.e. a set $M \subseteq W$) that is as robust as possible against coverings (i.e. we build a set of codewords that minimize covering phenomena).

It is defined as a triple (s, L, K) where L and s are integer numbers such that if I sum s codewords in M, the result r will cover at most L - 1 codewords among the remaining |M| - s.

i.e. there are at most L - 1 codewords in the subset $\{M - \{s\}\}$ such that $r \cap R w = r$.

Let N, t, s, and L be integers such that 1 < s < t, $1 \le L \le t - s$, and N > 1. Given a $N \times t$ binary matrix \mathcal{X} , denote the ith column of \mathcal{X} by X(i), where $X(i) = (x_1(i), x_2(i), \cdots, x_N(i))'$. We call X(i) a codeword i of \mathcal{X} with a length N. In other words, \mathcal{X} is a binary code with each column corresponding to a codeword.

Suppose $N, t, s, L \in \mathbb{Z}$ satisfies $1 < s < t, 1 \le L \le t - s, N - 1$, for a given binary matrix \mathcal{X} with size $N \times t$, the i - th column of $\mathcal{X}(i) = (x_1(i), x_2(i), \dots, x_N(t))'$ represents a binary code word numbered i. This kind of

Tools for choosing the Primary Channels (III)

- Lis called Reliability (or Overlap Bound). Why?
 - Choosing big values of L means admitting several coverages.
 - L = |M| s + 1 means admitting the coverage of at most the whole complementary set.
 - Computationally easy, but useless.
 - The optimal value is L = 1. (no codeword in the complementary set is ever covered). Such a Superimposed Code is called s-disjunctcode, and from now on we will assume to be given such a code.

Tools for choosing the Primary Channels (IV)

- s is called Strength. Why?
 - Choosing small values of s means that the sum of "few" codewords will cover at most one codeword among the remaining "many";
 - Choosing big values of s means that the sum of "many" codewords will cover at most one codeword among the remaining "few".
 - s = |M| 2 means that the sum of all the codewords but two will cover at most one of the remaining 2 codewords in the complementary set.

Tools for choosing the Primary Channels (V)

LEMMA 4.1. Given an (s, 1, N) superimposed code \mathcal{X} , for any s-subset of the codewords of \mathcal{X} , there exists at least one row at which all codewords in the s-subset contains the value 0.

PROOF. For contradiction we assume that there is no row at which all codewords in the s-subset contain a common value 0. Then the Boolean sum of the s codewords equals $(1, 1, \dots, 1)'$, which can cover all other codewords in \mathcal{X} , contradicting to the fact that \mathcal{X} is a superimposed s-disjunct code. \square

Xing et al - Channel Assignment via Superimposed Code (2007)

Tools for choosing the Primary Channels (VI)

Figure 1: An example of a superimposed (3, 1, 13)-code of size 13

Xing et al - Channel Assignment via Superimposed Code (2007)

A (3, 1, 13)-code is a 3-disjunct code, meaning you can sum any subset of up to s=3 columns of length N=13 and be sure the sum won't cover any of the remaining t-s=13-3=10 codewords.

N=t is not by chance: for small s w.r.t. N, we tend to have t proportional to N.

Choosing the Primary Channels (I)

- First, we equip every node in the network with an **s-disjunct code** \mathcal{X} . We set the length K of the codeword equal to the number of orthogonal channels k_i ;
- A generic node u randomly selects a codeword $\mathcal{X}(u)=\vec{c_u}$ from the $|\mathcal{X}|$ available options, e.g.

$$ec{c_u}=(100100101\cdots)$$

- The element $\vec{c_u}(i)$ represents channel k_i . Specifically, $k_i=1$ means that k_i is a candidate to become the primary channel $\mathrm{CH}_1(u)$ for node u;
- Each node broadcasts its pair { ID (e.g. a MAC Address), $\vec{c_u}$ }, and forwards the pairs of its neighbors so that every neighbor reaches is whole neighborhood.
 - It's more or less like a broadcast with TTL = 2.
- At this point, each node u knows the ID and the codeword chosen by every node in its neighborhood, which forms its **interference set** $\mathcal{N}(u)$, i.e., the nodes that must choose disjoint CH_1 to avoid mutual interference (i.e. a labeling L(1,1)).

Choosing the Primary Channels (II)

- It then calculates two elements:
 - BoolSum $(\mathcal{X}(\mathcal{N}(u) \cup u))$ All possible CH_1 in the neighborhood, **including** u;
 - BoolSum $(\mathcal{X}(\mathcal{N}(u)))$ All possible CH_1 in the neighborhood, **excluding** u.
- ullet Finally, the list of channels $\mathrm{CH}_1(u)$ is obtained from the **XOR** of these two

$$\operatorname{BoolSum}(\mathcal{X}(\mathcal{N}(u) \cup \{u\}) \oplus \operatorname{BoolSum}(\mathcal{X}(\mathcal{N}(u)))$$

Or, in a simpler way,

 $\mathcal{X}(u)$ AND (NOT BoolSum $(\mathcal{X}(\mathcal{N}(u)))$

How can we be sure we'll find at least one CH1? How do we know CH1 will be non-empty?

Choosing the Primary Channels (III)

Lemma 1. If $s \geq |\mathcal{N}(u)|$ and $\mathcal{N}(u)$ is the complete set of interferers of u for any node, the $CH_1(u)$ exists surely.

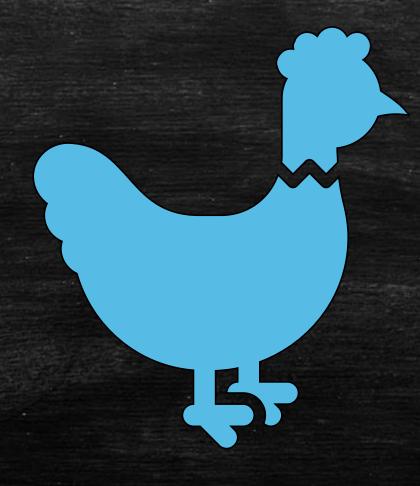
Proof. Since \mathcal{X} is an s-disjunct code, BoolSum $(\mathcal{X}(\mathcal{N}(u)))$ dose not cover $\mathcal{X}(u)$, which means that there exists at least one row in \mathcal{X} at which $\mathcal{X}(u)$ has the value 1 and all $\mathcal{X}(\mathcal{N}(u))$ have the value 0. Therefore the conclusion $CH_1(u) \neq \emptyset$ holds.

Xu et al-A New Channel Allocation Scheme for Vehicle Communication Networks (2014)

THEOREM 5.2. If $s \ge |\mathcal{N}(u)|$ and $\mathcal{N}(u)$ is the complete set of interferers of u for $\forall u$ in G, the channel assignment based on Algorithm 1 guarantees interference free communications in the network.

PROOF. Since \mathcal{X} is an s-disjunct code, $BoolSum(\mathcal{X}(\mathcal{N}(u)))$ does not cover X(u), which means that there exists at least one row in \mathcal{X} at which X(u) has the value 1 and all $\mathcal{X}(\mathcal{N}(u))$ have the value 0 (see Lemma 4.1). Therefore condition $CH_1(u) \neq \emptyset$ holds. Based on Theorem 5.1, the claim holds. \square

Uhm...





A New Channel Allocation Scheme for Vehicle Communication Networks

Jing Xu, Wei Li, Zan Ma, and Shuo Zhang (2014)



... also known as...

Superimposed Code Based Channel Assignment in Multi-Radio Multi-Channel Wireless Mesh Networks

Kai Xing, Xiuzhen Chen, Liran Ma, Qilian Liang (2007)

Just another meme, then we get back to work

"can I copy your homework?"

"yeah just change it up a bit so it doesn't look obvious you copied"

"ok"

Superimposed Code Based Channel Assignment in Multi-Radio Multi-Channel Wireless Mesh Networks

Kai Xing, Xiuzhen Cheng & Liran Ma Department of Computer Science The George Washington University Washington, DC 20052, USA {kaix,cheng,lrma}@gwu.edu

BSTRACT

Motivated by the observation that channel assignment for multiration multi-humsel methorshoods should support both miscurian and local Protocolom², should be interelerence-source, and should rebeatly a support of the control of the control of the control of the beatly support the local bookset and amount of filled apportions based on a disjunct support the local bookset and amount of filled apportion support the local bookset and amount of filled apportions and support the local bookset and amount of filled apportions and apportion of the control of the complete shallows, under the primary interference constraint², the channel assignment algorithm or ministed can achieve 100% filled point in deposition with a sample a booksidized apportion was a better and as a support of the control of the contro

Categories and Subject Descriptors C.2.1 [Network Architecture and Design]: Wireless Communi

cation

General Terms Algorithms, Design

Keywords

Multi-radio multi-channel wireless mesh networks, interference channel assignment, superimposed codes

A broadcast to be heard by all immediate neighbors.

Qilian Liang

Department of Electrical Engineering The University of Texas at Arlington Arlington, TX 76019, USA liang@uta.edu

1. INTRODUCTION

With recent advances in wireless technology, the utilization of multiple radios as well as non-overlapping channels provides an opportunity to reduce interference and increase network capacity. Equipped with multiple radios, nodes can communicate with multiple neighbors simultaneously over different channels, and thus can significantly improve the network performance by exploring concurrent transmissions [11].

In a multi-cadio multi-channel ORB-MO, much network, a ky challenging problem for capacity optimization is channel autisezneut. Since practically the number of radios at each node is always made and the contraction of the contraction, in many large problems to soon such as cost and small from factors, it may be problemier to each one with a officer or channels are made to the contraction. The need to within 3 officers channels as in tage for the better performance. This radio contrainst mades the channel assignment in MR-MC much networks much harlet. In this paper, we propose two channel assignment algorithms for interference mitigation and made to the contraction. Our treatenth is moviment by the feltowge observations.

- Current channel assignment approaches lack a support to le cal broadcast in MR-MC mesh networks. As neighborin nodes tend to use different channels for transmissions, if broadcast packet has to be separately transmitted by the sen on multiple channels. Thus, broadcast can be more expensition that in single-radio single-channel (SR-SC) networks.
- A number of current channel assignment approaches rely beavily on solving complex optimization problems, which might be impractical for many MR-MC mesh network secnarios. In addition, techniques based on default radio/channel degrade network throughput when the number of radios is much smaller than that of channels.
- Channel switching delay is an important parameter that she
 has counted in channel assistances. Since the number of

A New Channel Allocation Scheme for Vehicle Communication Networks

Jing Xu, Wei Li, Zan Ma, and Shuo Zhang

University of Science and Technology of China, Anhui, China 230027 {jxu125,weili011,sa612135,zshuo}@mail.ustc.edu.cn

Abstract. In roadway networks, the timely, reliable, and high-throughput transmission is particularly important to webliels, e.g., for roadway safety warning applications. However, it is difficult to achieve these goals at the same time in vehicle-to-vehicle communications due to mobility, interference, etc. In this paper, we tackle this issue and propose a new channel allocation scheme based on OFDM(Orthogonal frequency-division multiplexing). Our design can achieve highly reliable transmission through dynamically allocated interference free channels demanding on timeliness, and high throughput through secondary channels for information transmission insensitive to timeliness. In our evaluation study, the results show that our scheme can provide a guarantee for reliable and high-throughput transmission.

Keywords: vehicle networks, channel allocation, reliability

1 Introduction

With the increasing demand on high-data-rate wireless communication services, the bandwidth allocation design is expected to accommodate more users and support higher data rate on the guarantee of the quality of service. OFDMA is one of such communication systems. However, most existing OFDMA schemes are centralized and meet difficulties to satisfy users' requirements in which ent-

Primary Channels (Xu et al, 2014)

Algorithm 1. A distributed wireless channel allocation scheme for vehicle networks

Input: The initial information of each node u: C, ChEstimate(u), $N_1(u)$, NumCh(u) R(u), Rate(u).

Output: Each node u chooses its primary channel $CH_1(u)$ to send important information and the channel set $CH_2(u)$ to deliver large amounts of packets.

step 1: Each node broadcasts its ID and forward the received neighbor ID once, thus everyone will get the $\mathcal{N}(u)$.

step 2: $\forall u \in V, CH_1(u) =$

 $Channels(BoolSum(\mathcal{X}(\mathcal{N}(u) \bigcup \{u\}))) \bigoplus BoolSum(\mathcal{X}(\mathcal{N}(u)))$

 \triangleright find the primary channels for u, and secondary channels for $\mathcal{N}(u)$, then choose one to be the $CH_1(u)$.

Like we said, every node broadcasts its ID (i.e. its codeword) with TTL = 2.

Then, every u is able to perform the XOR operation to find the channels which are primary to u and not primary to any neighbor.

But this works only if we have at most s neighbors.

What if we happen to have more?

Primary Channels (Xing et al, 2007)

Here the idea is the following: we don't know if the numer of neighbors is lesser or equal than s. If that's not the case, we're not sure to find CH1 as we discussed so far.

In case this first approach fails, u may look for secondary channels which are secondary also to all its neighbors.

In case this second approach also fails, rely on the "lesser evil" choosing the "least-interference channel"

```
Algorithm 1 Channel Assignment for Node u
Input: Codewords X(u) and \mathcal{X}(\mathcal{N}(u)).
Output: CH(u), the set of channels assigned to u.
 1: function CH(u)=ChannelSelect(X(u), \mathcal{X}(\mathcal{N}(u)))
          CH_1(u) \leftarrow Channels(BoolSum(\mathcal{X}(\mathcal{N}(u) \cup \{u\})) \oplus
                BoolSum(\mathcal{X}(\mathcal{N}(u)))) > Find the set of primary channels
               that are secondary to all nodes in \mathcal{N}(u).
          if CH_1(u) \neq \emptyset then
               CH(u) \leftarrow CH_1(u)
               CH_2(u) \leftarrow Channels(\overline{BoolSum(\mathcal{X}(\mathcal{N}(u) \cup \{u\}))}) \quad \triangleright
                     Find the set of secondary channels that are secondary to
                     all nodes in \mathcal{N}(u).
               if CH_2(u) \neq \emptyset then
                     CH(u) \leftarrow CH_2(u)
 9:
                else
10:
                     CH_3(u) \leftarrow \text{Select } Channels(X(u)) \text{ with the smallest}

    Select the primary

                          row weight in \mathcal{X}(\mathcal{N}(u))
                          channels with the least row weight in \mathcal{N}(u).
                     CH(u) \leftarrow CH_3(u)
11:
12:
                end if
           end if
14: end function
```

Primary Channels (Xing et al, 2007)

Lemma 2. If the channel set u's first choice $CH_1(u) \neq \emptyset$, then u has no interference with its two-hop neighbor $\mathcal{N}(u)$.

Proof. Given that $CH_1(u) \neq \emptyset$, node u picks a channel $\alpha \in CH_1(u)$. And we know that form lemma \blacksquare in the \mathcal{X} , on the αth row,

$$\mathcal{X}(\alpha, u) = 1, but \quad \mathcal{X}(\alpha, \mathcal{N}(u)) = 0 \qquad (\forall v \in \mathcal{N}(u))$$

In other word, the channel α is primary to u, and secondary to $\mathcal{N}(u)$. So node u can pick up a channel α from $CH_1(u)$, which will not be in interference with $\mathcal{N}(u)$.

LEMMA 5.1. If $CH_1(u) \neq \emptyset$, node u does not interfere with any other node in $\mathcal{N}(u)$.

PROOF. When $CH_1(u) \neq \emptyset$, node u picks up channels from $CH_1(u)$, a subset of u's primary channel set, for transmission. $CH_1(u)$ contains channels that are primary to u but secondary to all nodes in $\mathcal{N}(u)$. For $\forall v \in \mathcal{N}(u)$, v can't use any channel from $CH_1(u)$ based on Algorithm 1 since v is assigned with either its own primary channels (from $CH_1(v)$ or $CH_3(v)$), which can't be in $CH_1(u)$, or channels that are secondary to all interferers in $\mathcal{N}(v)$ ($CH_2(v)$), which are secondary to u too since $u \in \mathcal{N}(v)$. \square

Some of the phrases and theorems that made no sense in Xu et al (2014) suddenly become clear in the framework given by Xing et al (2007).

What about the Secondary Channels?

Weren't we supposed to assign some secondary channels via some greedy algorithm?

Glad you asked.

Xing et al (2007) never mentions such an assignment, so this must be some original work.

It is. And it makes no sense.

step 3: $\forall u \in V$, $AvaliableCH(u) = C - \sum_{v \in (\{u\} \cup \mathcal{N}(u))} CH_1(v)$. (C represents the whole channel set) step 4: $\forall u \in V$, $Priority(u) = \frac{R(u)}{Rate(u)}$, and send it to their $\mathcal{N}(u)$. step 5: $\forall u \in V$, $Sort(Priority(v)), v \in (u \cup \mathcal{N}(u))$, thus we can get each node u's priority order Seq(u) among the nodes in $\mathcal{N}(u)$. step 6: Token = 1; step 7: $\forall u \in V$, if $Seq(u) = Token : CH_2(u) =$ the highest NumCh(u) channels on the value of Estimate(u) among the Available(u).

if
$$|CH_2(u)| < NumCh(u)$$

then Pritority(u) Add endif

Token = Token + 1 endif.

step 8: if there exists any node u which has not been involved in the allocation scheme, turn to step 7;

else break;

Choosing the Secondary Channels (I)

In brief, the idea behind the assignment is the following.

Every node has an idea of its throughput needs and of its transmission speed. Based on this, we can compute a *Priority* value for choosing the best secondary channels among the available ones.

The evaluation of the "best" is based on some metrics given by a function called ChEstimate (or sometimes, randomly, just Estimate).

Then, we initialise a global variable named Token and we loop over all the possible nodes u of the graph. Each node loops over Token, so that when the Sequence value (computed by means of Priority) is equal to the Token I can choose the best channels available. Somehow, it may happen that a node can't get enough channels. In this case, we just Priority Add (whatever it means, since it's the only occurrence in the whole paper). Even though this should be the core operation

Choosing the Secondary Channels (II)

... let's say it has a bunch of problems.

Half of the functions are never defined (e.g. NumCh, ChEstimate).

Being a global variable, Token makes this a centralized algorithm, instead of a distributed one (moreover, it lacks the typical syncronization mechanisms of distributed systems, like ACKs).

It is unclear how " $CH_2(u) = the \ highest \ NumCh(u) \ channels \ on the \ value \ of \ Estimate(u) \ among \ the \ Available(u)$ " and then " $if \ |CH_2(u)| < NumCh(u)$ ".

It is unclear how "Pritority(u) Add". It's not even used in the loop.

OFDMA is never even mentioned but in the Introduction and in the Conclusions.

Choosing the Secondary Channels (III)

If we go back to Xing et al (2007), like we said, there's no such an assignment.

By Occam's Razor, we simply don't assign the secondary channels. Each node can rely on them for transmissions of lesser importance (e.g. infotainment), accepting the risk of interference.

At least, as long as no one provides A New Channel Allocation Scheme for Vehicle Communication Networks.

Conclusions

A simple, light and distributed scheme for finding an approximate solution to the L(1,1) interference-free primary channel assignment is achieved by means of an s-disjunct code respecting some further conditions.

Secondary channels for high throughput transmissions have to deal with some interference.

One should always check the References if something looks weird.

Since 41.59 is "very close" to 40, Xu et al's conclusions are "correct and realistic".

Actually,we make a statistics about the real probability on the Section 5 In our experiment, K = 13, $\mathcal{N}(u) = 4$, so the probability $\frac{K(K-1)\cdots(K-\mathcal{N}(u))}{K^{\mathcal{N}(u)+1}} = 41.59\%$. The practical result is 40%, which proves our conclusion is correct and realistic.