Dynamic Multiple-Message Broadcast: Bounding Throughput in the Affectance Model

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Introduction

Dynamic Multiple-Message Broadcast (MMB) [1]:

- *problem*: packets arrive at nodes **continuously**, to be delivered to **all** nodes
- *metric*: **competitive throughput** of deterministic distributed MMB algorithms
- *analysis*: in **general Affectance model**:
  - Affectance subsumes many communication-interference models
    e.g. RN and SINR models
  - conceptual idea: parameterize interference from transmitting nodes into links
  - introduced [2,3,4] for link scheduling as link-to-link affectance

[1] (non-dynamic MMB) Khabbazian-Kowalski PODC 2011
[2] Halldórsson-Wattenhofer, ICALP 2009
[3] Kesselheim, PODC 2012
[4] Kesselheim-Vöcking, DISC 2010

Introduction

- Contributions:
  - we introduce new model characteristics:
    (based on comm network, affectance function, and a chosen BFS tree)
    - **maximum average tree-layer affectance** K
    - **maximum fast-paths affectance** M
  - we show how characteristics influence broadcast time complexity:

    if one uses a specific BFS tree (GBST [1]) that minimizes $M(K+M)$

    single broadcast can be done in time $D + O(M(K+M)\log^3 n)$
  - we extend this to dynamic packet arrival model and the MMB problem:

    new algorithm reaching throughput of $\Omega(1/(\alpha K \log n))$
  - ... also simulations for RN

[1] Gąsieniec-Peleg-Xin, DC 2007

Introduction

- Observations:
  - throughput measured in the limit $\Rightarrow$
    preprocessing is free $\Rightarrow$ protocol is distributed
  - deterministic results are existential (protocol includes randomized subroutine)
  - can also be applied to mobile networks,
    if movement is slow enough to recompute structure
  - To the best of our knowledge,
    first work on dynamic MMB under the general Affectance model

The General Affectance Model

Interference:

- 1-hop:
  - Radio Network model without collision detection
- ($\geqslant 1$)-hop:
  - value $a_u(\ell) \leqslant 1$ quantifies interference of node u on link ℓ
  - $a_u((u,v)) = 0$, $a_v((u,v)) = 1$, and $a_w((u,v)) = 1$, $w \in N(v)$ and $w \neq u$
  - $a_\cdot(\cdot)$ is any function s.t. $a_{\{u,v\}}(\ell) = a_{\{u\}}(\ell) + a_{\{v\}}(\ell)$
  - affectance degradation parameter α

Successful transmission:

- transmission from u is received at v iff
  - u transmits
  - v listens
  - $a_T((u,v)) < 1$, where $T = \{\text{set of nodes transmitting}\}$

Injection and Performance Metric

Feasible adversarial injections: $\exists$ OPT with bounded packet latency.

At most 1 packet may be received by a node in each time slot
and all nodes must receive the packet in order to be delivered
$\Rightarrow$ feasible adversarial injection rate at most 1 packet per time slot.

Performance metric: competitive throughput in the limit

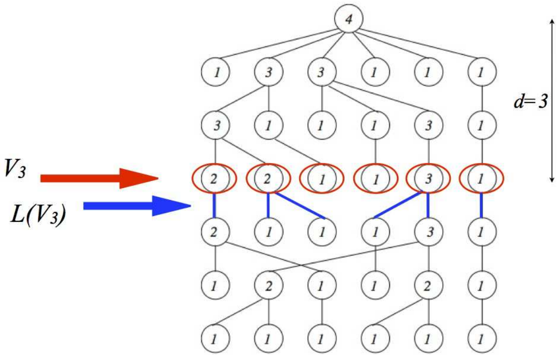
$$\exists f : \lim_{t\to\infty} \frac{d_{ALG}(t)}{d_{OPT}(t)} \in \Omega(f)$$

Affectance Characterization

Maximum average tree-layer affectance

Quantifies the difficulty to disseminate from one layer to the next one.

$$K(T, s) = \max_{d} \max_{V' \subseteq V_d(T)} \frac{a_{V'}(L(V'))}{|L(V')|}$$

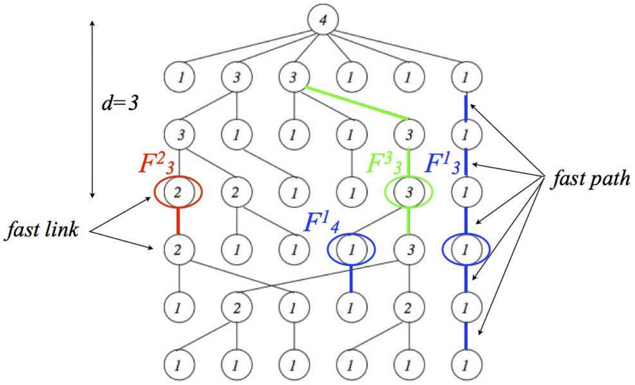


Affectance Characterization

Maximum fast-paths affectance

Quantifies the difficulty for dissemination on a path due to other paths.

$$M(T,s) = \max_{d,r} \max_{\ell \in F^r_d(T)} a_{F^r_d(T)}(\ell)$$



Low-Affectance Broadcast Spanning Tree (LABST)

- Tree construction:
  1. $T_{\min} \leftarrow \arg\min_{T \in GBST(s)} M(T,s)(M(T,s)+K(T,s))$
  2. $T_{\min} \rightsquigarrow$ LABST T

     T avoids links between nodes of the same rank with big affectance

     blowing up GBST ranks by a $M(T)$ multiplicative factor
- Broadcast schedule: defined using the ranks in T

Low-Affectance Broadcast Spanning Tree (LABST)

Corollary

For any given network of $n \geqslant 8$ nodes and source s, diameter D, and affectance degradation distance $\lceil \log n \rceil$, there exists a broadcasting schedule of length

$$D + O(M(T_{\min}, s)(M(T_{\min}, s) + K(T_{\min}, s)) \log^3 n)$$

For comparison, in Radio Networks: $D + O(\log^3 n)$ [1]

$O(D + \log^2 n)$ [2]

[1] Gąsieniec-Peleg-Xin, DC 2007

[2] Kowalski-Pelc, DC 2007

MMB Protocol

- define LABST from each source node
- define a MBTF [1] list of source nodes
- assign a token to some source node from list

1. upon receiving the token at node s
2. if $queue(s)$ is “empty”:
    1. pass token to next in list
3. else if $queue(s)$ is “small”:
    1. disseminate Δ packets pipelined with period δ
    2. pass token to next in list
4. else if $queue(s)$ is “big”:
    1. move s to front of list
    2. while $queue(s)$ is “big”: disseminate Δ packets pipelined with period δ
    3. pass token to next in list

[1] Chlebus-Kowalski-Rokicki 2009

MMB Protocol Analysis

Lemma

There exists a MMB protocol that achieves a throughput ratio of at least

$$\lim_{t\to\infty} \frac{1}{1+\delta} - \frac{2\Delta n^2}{t}$$

Corollary

For any given network of n *nodes, diameter* D*, affectance degradation distance* α*, and* $K = \max_{s\in S} K(T_{\min}(s), s)$*, there exists a MMB protocol such that the throughput ratio converges to*

$$\frac{1}{O(\alpha K \log n)}$$

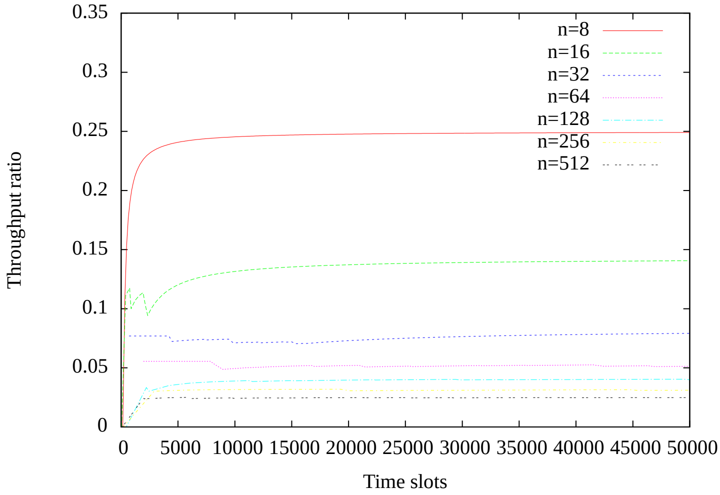
For comparison, in Radio Networks:

- using WEB protocol [1] for propagation converges to $1/O(\log^2 n)$
- $O(1/\log n)$ for any single-instance MMB algorithm [2]

[1] Chlamtac-Weinstein 1987

[2] Ghaffari-Haeupler-Khabbazian 2013

Simulations



Thank you