JIM-Beam: Using Spatial Randomness to Build Jamming-Resilient Wireless Flooding Networks

Jerry T. Chiang
Advanced Digital Sciences Center
Singapore
jerry.chiang@adsc.com.sg

Dongho Kim
University of Illinois at Urbana–Champaign
Urbana, IL, USA
dkim99@illinois.edu

Yih-Chun Hu
University of Illinois at Urbana–Champaign
Urbana, IL, USA
yihchun@illinois.edu

ABSTRACT

Since a transmitter can only be at one location at a time, a jammer must jam in a narrowband fashion in the spatial domain. We propose JIM-Beam, a narrowband jamming-resilient flooding protocol that randomizes the orientation of a node's directional antenna over time. We use ns-2 simulations to show that JIM-Beam provides improvements in packet delivery ratio over flooding naïvely and flooding using the uncoordinated frequency hopping protocol.

Categories and Subject Descriptors

C.2.1 [**Network Architecture and Design**]: Wireless communication

Keywords

availability, flooding network

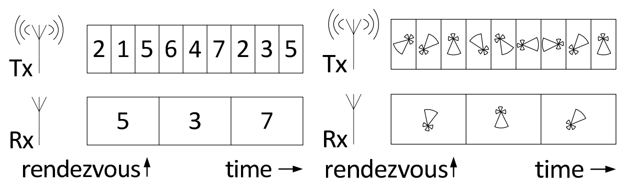
1. INTRODUCTION

Wireless network protocols, such as routing or key assignment, often use *flooding* first to ensure packet delivery to all reachable network nodes. Jamming-resilient flooding is thus crucial in providing long-term network performance.

Strasser et al. propose the Uncoordinated Frequency Hopping (UFH) scheme in which a transmitter and a receiver each selects a random channel to transmit and to listen, respectively [4]. When the transmitter and the receiver *rendezvous*, the receiver is able to receive the transmission. Fig. 1(a) illustrates the UFH scheme.

We borrow the *randomization* concept from UFH and propose a flooding protocol that uses directional antennas: Each network node reorients its directional antenna toward different and randomly selected directions at different times. A node can reorient its directional antenna either mechanically (like a radar) or electrically (e.g. by array reformation or antenna reconfiguration [1]). Fig. 1(b) illustrates our protocol, which we name *JIM-Beam*: Jamming and Interference Mitigation using Beam antennas.

JIM-Beam provides one advantage over UFH: Since each adversarial transmitter can only be in a single place at any instance in time, it can only attack in a *narrowband* fashion in the spatial domain. We assume that no adversary can react to future events or authenticate forged messages.



(a) UFH, numbers denote chosen frequency channels

(b) JIM-Beam, patterns denote chosen antenna orientations

Figure 1: Illustration of UFH and JIM-Beam

2. RELATED WORK

Several previous studies propose using directional antennas to reduce interference. Sani et al. proposed adaptively changing the directional antenna orientation in order to minimize the received interference [3]. Noubir used sectored antennas, and studied the theoretic minimum number of jammers to reduce the network connectivity index to 0 [2].

Strasser et al. proposed the UFH scheme [4]. JIM-Beam borrows the randomization concept from UFH and randomizes the orientation of each node's directional antenna.

3. JIM-BEAM FLOODING PROTOCOL

In the JIM-Beam protocol, each node is equipped with a directional antenna. If a node receives a packet it has not seen before, the node rebroadcasts the packet B times so other nodes can receive the packet and pass it on. Before a node wants to transmit a packet, either to initiate a new flood or to forward a packet, the sender backs off by choosing a backoff counter BC randomly, $\mathrm{BC} \xleftarrow{r} [0, \mathrm{BC}_{\max}]$ (where $\mathrm{BC}_{\max}$ is a system parameter), and transmitting using the directional antenna after BC time slots. JIM-Beam does not require a wideband spectrum to provide jamming resiliency.

4. EVALUATION

4.1 Methodology

We implement JIM-Beam, UFH, and naïve flooding in ns-2 to compare these protocols. We augment the original ns-2 with a directional antenna patch[1]. We let each node reorient its directional antenna every one second. We equip each simulated node with a home-made cantenna, which is built using a Pringles can such that the can is able to rotate

[1]source code at: http://cbg.me/2009/02/adding-directional-antenna-and-multiple-interface-support-to-ns-233/

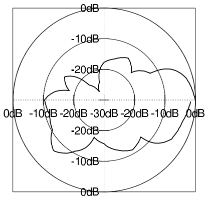
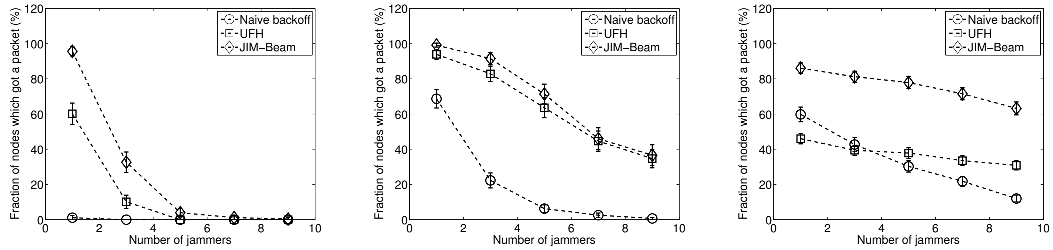


Figure 2: Radiation pattern of cantenna



(a) Field dimension = 500 × 500 m (b) Field dimension = 1500 × 1500 m (c) Field dimension = 4000 × 4000 m

Figure 3: Packet delivery ratio versus the number of jammers

about the line feed. Fig. 2 shows the radiation pattern of our cantenna, which has maximum directivity of 7.244. Our JIM-Beam implementation uses only one frequency channel.

To implement UFH, we augment the ns-2 packet structure with a "channel number" field, and let each node randomly choose one of eight frequency channels every one second. A UFH receiver then discards any incoming packet not bearing the channel number matching that of the receiver.

We assume each jammer uses an omni-directional antenna and has the same transmission power as a benign node. We further assume each jammer spreads his power evenly across all available frequency bands; this represents a best case scenario since a reactive jammer can always degrade the network performance more.

We place 100 benign nodes uniformly randomly on the field, and similarly place one to nine additional jammers on the field. The source node broadcasts a 256-byte packet. We simulate three field dimensions: 500×500 m, 1500×1500 m, and 4000×4000 m. Since the number of benign nodes are fixed, the results capture the performance of the flooding protocols with respect to node density.

When a node receives a new data packet, the node relays that packet with parameters $B = 50$ and $\mathrm{BC}_{\max} = 2000$ sslot, where sslot $= 2$ ms is a *small slot*. We simulate each scenario 250 times, each 100 simulated seconds in duration, and measure the packet delivery ratio (PDR), i.e. the fraction of benign nodes that receive the broadcast packet.

4.2 Simulation Results

Fig. 3 shows the PDR versus the number of jammers, and compares the results between: 1. JIM-Beam; 2. UFH; and 3. naïve flooding. We plot a different curve for each scheme; and a different plot for each field size. With all protocols, intuitively, the PDR decreases in the number of jammers.

The results also show that the performance of the protocols depends on the density of the network. In networks with high and medium node density, JIM-Beam offers better but similar performance as UFH. In sparse networks, JIM-Beam significantly outperforms UFH using the same transmission power since the directional antenna extends a JIM-Beam node's transmission range.

5. JAMMING RESILIENCE OF JIM-BEAM

For ease of analysis and only for this section, we analyze the security of JIM-Beam assuming each receiver is equipped with a *sectored antenna* with solid beam-width Ω. Let each packet be t in duration and with 0 error correcting capability.

If the jammer wishes to corrupt a data packet with probability p, the jammer needs to make at least $p - (2\Omega)/360^\circ$ of a revolution around the receiver within time t, usually resulting in an unrealistically high centripetal force.

6. CONCLUSION

We propose a flooding protocol that uses random antenna orientation to mitigate the jamming attack. One particular benefit of using directional antennas to reject interference is that jammers cannot perform the equivalent of wide-band jamming, since the location of each malicious node is a single-source of interference. We also show that the jamming resilience of JIM-Beam comes from physical, and not computational, restrictions.

We use ns-2 simulations to evaluate the effectiveness of the JIM-Beam protocol. Our results show that JIM-Beam can significantly outperform flooding naïvely or flooding using the UFH protocol.

7. ACKNOWLEDGMENTS

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