Concurrent Multipath Traffic Distribution in Ad Hoc Networks based on Attractor Perturbation

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Contributions

In this study, we present a novel bio-inspired traffic distribution method based on *attractor perturbation* (AP) for concurrent multipath transmission. It can reduce both the average and the variance of packet delays under stable traffic conditions and sudden traffic change using only end-to-end delays and traffic rates. Moreover, the AP model allows viewing the underlying network as a black box.

Introduction

As computer networks become more complex, network control protocols often rely heavily on the complete knowledge of current network status and the preconfigured parameters, which make them less flexible to unpredicted conditions. The concept of biologically inspired networking has been introduced to cope with unpredictable or unstable situations in computer networks because it can generally provide a high degree of robustness and adaptability.

In ad hoc networks, it is commonly known that transmissions over wireless channels suffer from radio propagation loss, shadowing, fading, radio interference, and limited bandwidth. In this study, we focus on *solving the limited bandwidth problem* in which one of the most common approaches is *using multiple paths concurrently*.

By utilizing a biological mechanism called *attractor perturbation* (AP), only two end-to-end parameters, i.e., traffic rate and delay statistics on each path, are required to perform a traffic distribution over multiple paths. However, we also include packet loss in the implementation to further improve the performance of our proposal. As biological mechanisms are well-known for their high robustness and adaptability, we expect the AP-based method to be robust and adaptive to new environment and unexpected conditions without the need of re-tuning parameters to accurately fit in the new situations.

Attractor Perturbation

The attractor perturbation model is derived from observations of fluctuation and response in biological systems. Sato et al. found that the fluctuation, which is expressed by the variance of the fluorescence of a bacterial protein, and its response, which is the average change in this fluorescence, have a linear relationship modeled as follows when a force Δa is introduced:

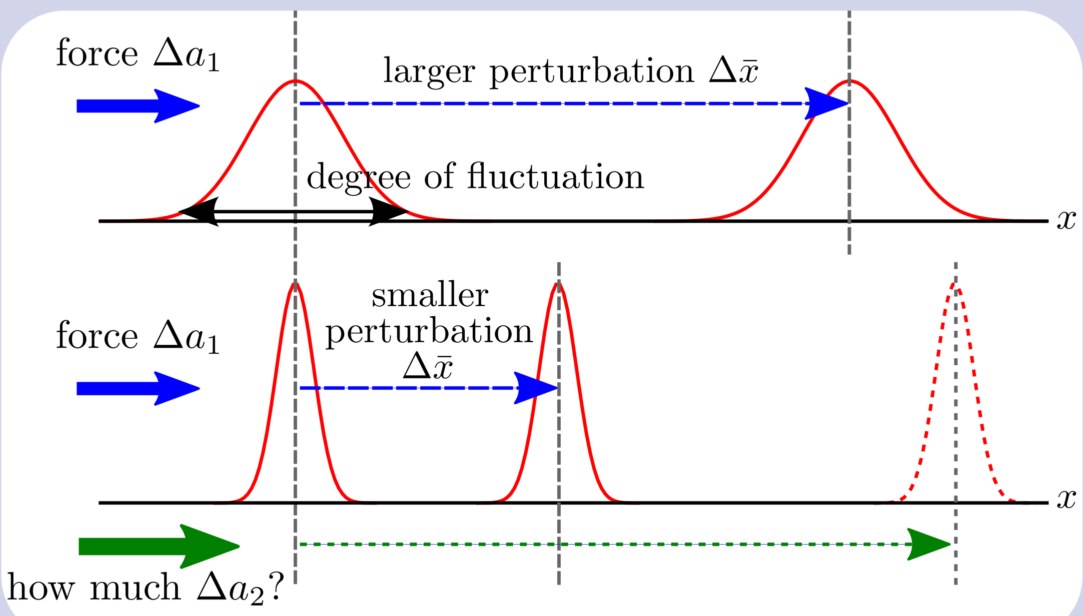


Fig.1 Attractor Perturbation Relationship

$$\bar{x}_{a+\Delta a} - \bar{x}_a = b\,\Delta a\,\sigma_a^2 \qquad (1)$$

where b is a scalar constant, x is a time dependent measurable variable in the system with mean $\bar{x}$ and variance σ_a^2, and a is a controllable parameter. The relationship in Eqn. (1) is illustrated in Fig. 1.

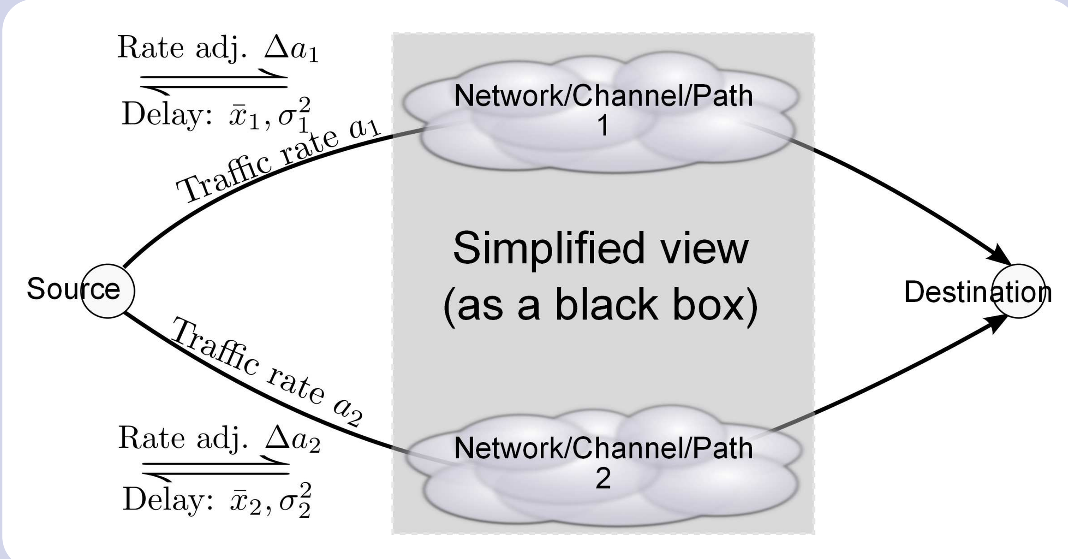


Fig.2 Overall System Model

Method

In this study, we consider a network with n paths between sources and destinations where each path i does not cause interference with one another, as illustrated in Fig. 2.

The notations are as follows: each path i has

- a_i: current traffic rate
- Δa_i: traffic rate change
- $\bar{x}_i$: average end-to-end delay prior applying Δa_i
- $\bar{x}'_i$: average end-to-end delay after applying Δa_i
- n_i: delivered packet count

Our proposal aims at minimizing the average end-to-end delay of all packets. Using AP, we attempt to minimize the *total delay sum*, which directly corresponds to the average delay of all packets on both paths. The delay sum can be estimated through the product of the expected delay and the adjusted traffic rate on each path.

According to the AP concept, in case of n paths we have:

$$\begin{aligned}\bar{x}'_1 &= \bar{x}_1 + b_1\Delta a_1\sigma_1^2\\ \bar{x}'_2 &= \bar{x}_2 + b_2\Delta a_2\sigma_2^2\\ &\vdots\\ \bar{x}'_n &= \bar{x}_n + b_n\Delta a_n\sigma_n^2\end{aligned}$$

Total delay sum can be calculated as follows:

$$\begin{aligned}&f(\Delta a_1, \Delta a_2, \ldots, \Delta a_n)\\ &= (a_1+\Delta a_1)\,\bar{x}'_1 + \cdots + (a_n+\Delta a_n)\,\bar{x}'_n\\ &= \Sigma_i^n[a_i\bar{x}_i + (\bar{x}_i + a_i b_i\sigma_i^2)\Delta a_i + (b_i\sigma_i^2)\Delta a_i^2]\end{aligned}$$

The minimization problem, which is solvable by using Lagrangian, can be formulated as follows:

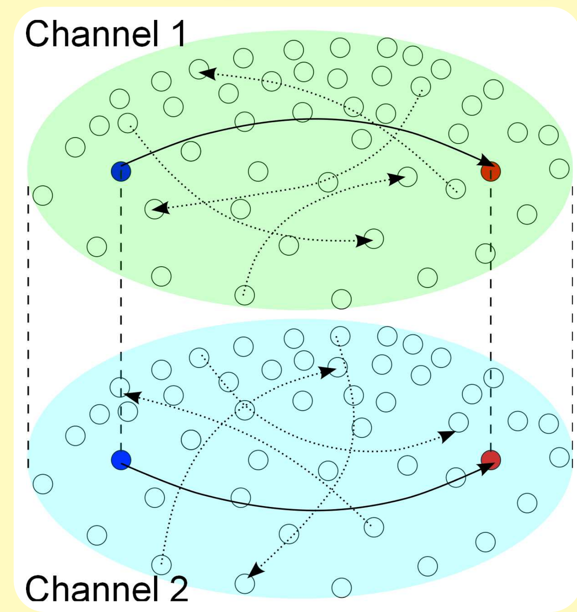
$$\textit{Minimize}\ \Sigma_i^n[a_i\bar{x}_i + (\bar{x}_i + a_i b_i\sigma_i^2)\Delta a_i + (b_i\sigma_i^2)\Delta a_i^2]$$
$$\textit{subject to}\ \Sigma_i^n \Delta a_i = 0$$

Optimal solutions are used in the following algorithm.

procedure ADJTRAFFIC($\bar{x}_1, \sigma_1^2, a_1, n_1, \bar{x}_2, \sigma_2^2, a_2, n_2$)
  for all i **do**
    $\bar{x}_i \leftarrow (\rho(\rho a_i - n_i) + \bar{x}_i n_i)/\rho a_i$ ▷ Compensate delay of each lost packet by the interval $\rho = 5$ s
  end for
  $(\Delta a_1^*, \Delta a_2^*) \leftarrow$ SolveMinimization($\bar{x}_1, \sigma_1^2, \bar{x}_2, \sigma_2^2$)
  if $|\Delta a_1^*| > 10\% \times (a_1 + a_2)$ **then**
    $\Delta a_1^* \leftarrow 10\% \times (a_1 + a_2) \times \frac{\Delta a_1^*}{|\Delta a_1^*|}$
    $\Delta a_2^* \leftarrow -\Delta a_1^*$ ▷ Rate change step $\leq 10\%$
  end if
  $a_1 \leftarrow a_1 + \Delta a_1^*$
  $a_2 \leftarrow a_2 + \Delta a_2^*$
end procedure

Evaluation Scenario

There are 50 nodes with two 802.11b (data rate 2 Mbps) interfaces, placed randomly in a 1500x1500 m^2 area.

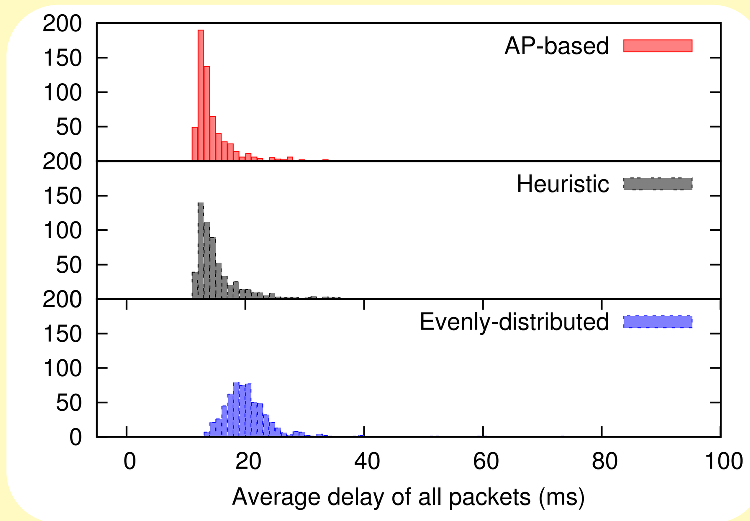


Each interface connects to a different radio channel. The main traffic session (<u>main</u>: 20 packets/s) is sent over both channels to the same destination on different interfaces, starting with an equal rate on both channels. There are 4 background traffic sessions (<u>bg</u>: 1 packets/s) on each channel. Additional 2 sessions (<u>added</u>: 10 packets/s) are added on one channel and switch to the other channel to create the need of traffic redistribution.

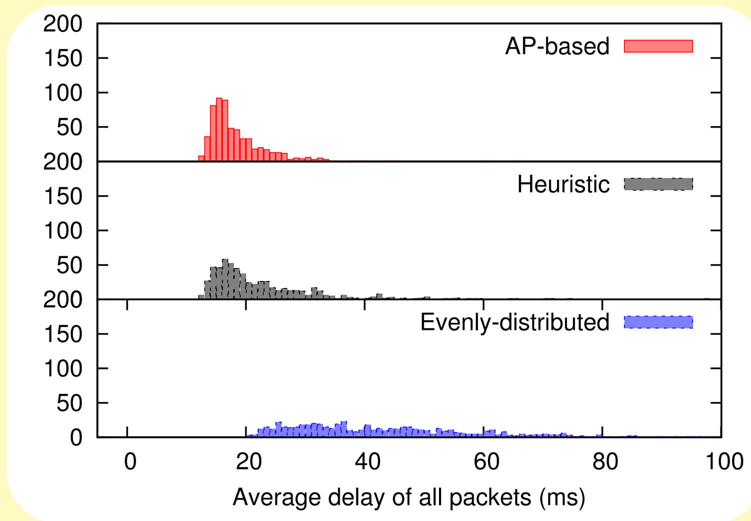
We used QualNet simulator and compared our proposal with a heuristic method which shifts 1% of the total traffic from the path with higher average delay to the lower delay path.

Results

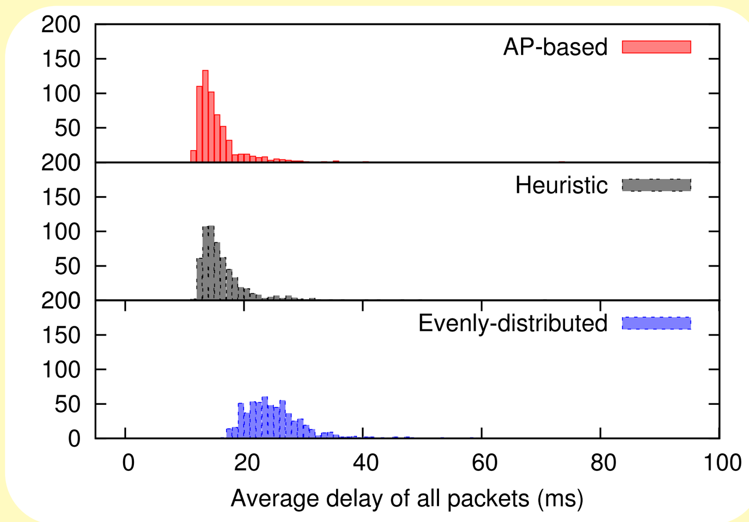
(a) When the traffic load on both wireless channels remains <u>equal</u>



(b) When the additional traffic load is <u>added</u> to the second channel



(c) When the additional traffic load is <u>switched</u> to the first channel



It can be seen that both AP-based and heuristic methods can lower the average delay than the evenly distributed case. The transition from Fig.(a) to Fig.(b) reveals a slower adaptation of the heuristic method; it keeps on using the path that became congested due to the additional traffic. However, by using both delay average and variance to quickly estimate the required amount of traffic change, AP-based method has a slightly better average delay and variance under all cases.

Note that due to space limitation, results with different coefficients b and heuristic shifted traffic step sizes are omitted. While different b does not affect our proposal performance much, we have chosen the best performing heuristic step size and show the results here.