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

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Abstract—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 this paper, we introduce a new concept, called attractor perturbation (AP), which is derived from observations of fluctuation and response in biological systems. Based on AP, we can estimate the resulting average response of an additional control effort (force) using the previously observed average and variance. In our concurrent multipath traffic distribution proposal, we observe delay statistics and adjust the traffic rate on each path, as a force. Based on the simulation results, our proposal not only lower the average end-to-end delay but also maintain the lower delay variance over changing background traffic patterns.

## I. Introduction

It is commonly known that transmissions over wireless channels suffer from radio propagation loss, shadowing, fading, radio interference, and limited bandwidth. Therefore, a lot of research attempts have been made in every layer and even across layers to improve the performance of communications in ad hoc networks. However, most improvements consider only the existing problems and lack flexibility towards emerging problems, especially the highly focused cross-layer optimization becomes less extensible and difficult to maintain [1].

In terms of bandwidth improvement, one of the most common approaches is using multiple paths in the same or across different media (multihoming). To enable the ability to utilize multiple paths concurrently, there are a few existing work in both wired, e.g., Opportunistic Multipath Scheduling (OMS) [2], and wireless networks, e.g., Concurrent Multipath Transfer (CMT) [3] and Adaptive Load Balancing Algorithm (ALBAM) [4]. However, most existing control methods require a full knowledge of current network status, e.g., queue length on each node, which is difficult to obtain.

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.

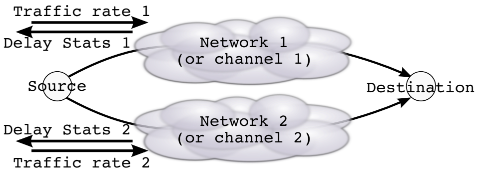


Fig. 1. Overall System Model

## II. Attractor Perturbation-based Traffic Distribution

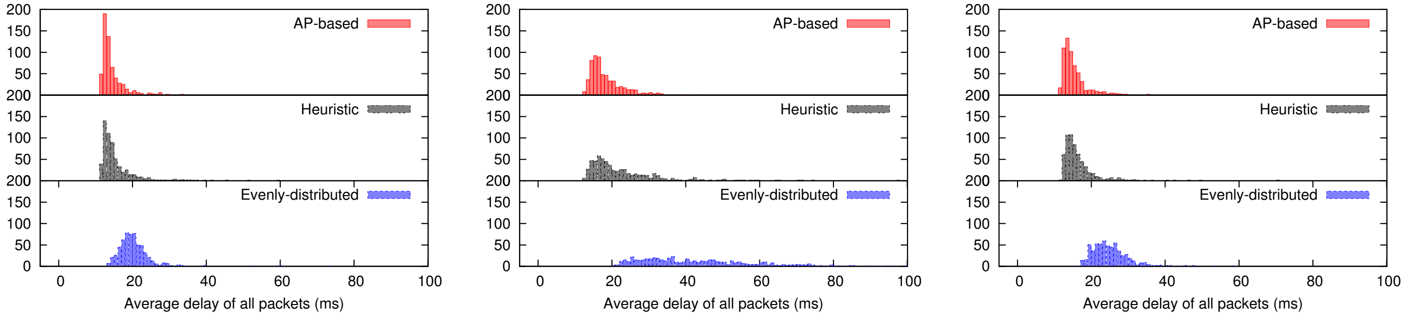
The attractor perturbation model is derived from observations of fluctuation and response in biological systems. In [5], it was found that the fluctuation, which is expressed by the variance of the fluorescence of a bacterial protein, and its response, which is the average change in this fluorescence, have a linear relationship modeled as follows when a force $\Delta a$ is introduced:

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

where $b$ is a scalar constant, $x$ is a time dependent measurable variable in the system with mean $\bar{x}$ and variance $\sigma_a^2$, and $a$ is a controllable parameter.

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. 1. This network model covers both ad hoc (or mesh) networks with multiple radio channels and also multihoming system. For the sake of simplicity, we consider only $n = 2$ in this paper. The notations are as follows: each path $i$ has 1) $a_i$: current traffic rate, 2) $\Delta a_i$: traffic rate change, 3) $\bar{x}_i$: average end-to-end delay prior applying $\Delta a_i$, 4) $\bar{x}'_i$: average end-to-end delay after applying $\Delta a_i$, and 5) $n_i$: 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. Therefore,



(a) Equal load on both paths t:0–3000 (b) More load on the second path t:3000–6000 (c) More load on the first path t:6000–9000

Fig. 2. Histogram of average delay, b=0.001

the minimization problem can be formulated as in Eqn. 2 and can be solved using Lagrangian. Moreover, Eqn. 2 can be easily extended to cases with $n > 2$.

$$\begin{aligned} &\text{Minimize} \\ &f(\Delta a_1, \Delta a_2) = \Sigma_{i=1}^{2} \left[ (\bar{x}_i + b_i \Delta a_i \sigma_i^2) \times (a_i + \Delta a_i) \right] \quad (2) \\ &\text{subject to} \quad \Sigma_{i=1}^{2} \Delta a_i = 0 \end{aligned}$$

The optimal solution $\Delta a_i^*$ from Eqn. 2 is used in the following procedure (Alg. 1), executed at the source every $5\,s$. Currently for simplicity, we assume that the end-to-end delay and the delivered packet count are known to the source without the need of issuing extra control packets.

Algorithm 1 AP-based Traffic Distribution

```
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
```

## III. Evaluation

As a preliminary evaluation, 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 path with lower one. The heuristic traffic adjustment is executed every 5 s, the same as our proposal. In case of $n_i = 0$, the traffic is shifted from the path with higher packet loss to the other one; this is also used in our proposal.

The scenario has 50 nodes with two 802.11b (data rate 2 Mbps) interfaces, which are placed randomly in a $1500 \times 1500\,m^2$ area. Each interface connects to a different radio channel and AODV is used on both interfaces. The main traffic session is sent over both channels to the same destination on different interfaces. The main traffic session has the total rate of 20 packets/s starting with equal rates on both channels. There are 8 background traffic sessions (4 on each channel) with the rate of 1 packets/s each. Additional 2 sessions (10 packets/s) are added at 3000 s on one channel and switch to the other channel at 6000 s to create the need of traffic redistribution.

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 in Fig. 2. 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. 2(a) to Fig. 2(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.

## IV. Conclusion and Future Work

We presented a novel bio-inspired traffic distribution method based on attractor perturbation. It can reduce both the average and variance of packet delays under stable traffic conditions and sudden traffic change using only end-to-end delays and traffic rates. Comparison of our proposal with [3] or [4] is left as a future work.

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