Zone-based congestion detection and control using routing method on the internet

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Abstract: The rapid growth of information technology has resulted in severe congestion problems in the internet. Due to micro-level congestion (such as link and router), it is hard to detect and control the congestion from the internet. To reduce and/or overcome this problem, we introduce, a macro-level congestion detection mechanism and congestion control method across the internet. Here, a zone is a collection of hundreds or thousands of networks situated in a geographical region. A zone has a zone-manager and border routers; they can cooperate with each other by controlling information. Using our method, zones can prevent congestion and produce better zone performance.

Keywords: network performance metrics; zone performance metrics; congestion control; zone-based congestion control; zone-based QoS.

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1 Introduction

Congestion control is the most important problem in the field of distributed system in the internet. The internet is the network, which is the interconnection of many networks. The internet users are increasing rapidly. Therefore, networks become busy and congested. Congestion occurs when the offered load exceeds the capacity of a data communication path (Allman et al., 1999). There are many reasons about the cause and the solutions of congestion control. Some are summarised as follows:

- Congestion is caused by the shortage of available network resources (links, routers, etc.). The problem will be solved when the cost of memory becomes cheap enough to allow very large memory. Larger buffer size is useful only for very short-term congestions and will cause undesirable long delays. Thus larger buffer size can only postpone the discarding of cells but cannot prevent it. The long queue and long delay introduced by large memory are undesirable for some applications.
- Slow processors of routers cause congestion.
  The problem will be solved when processor speed is improved. Faster processors will transmit more data in unit time. If several nodes begin to transmit to one destination simultaneously at their peak rate, the target will be overwhelmed soon.

To minimise and/or overcome the above-mentioned problems, one of the most important solutions is routing-based congestion control. Routing is a process of moving packets from one network to another. Presently, routing-based congestion control is being used at micro-level (such as links or routers); it is hard to detect where the congestion happens, because there may be hundreds/thousands of links or routers between source and destination. Therefore, we consider Zone-Based Routing (ZBR) for congestion detection and control on the internet.

A zone is a collection of hundreds or thousands of networks in a geographical region. It can provide dynamic network status (utilisation), resource availability (bandwidth availability), dynamic routing, load balancing, etc. A zone has a zone manager and border routers. They cooperate with each other by exchanging control information. Zone is quite necessary, as it has:

- *scalability*: zone map
- *efficient use of resources*: as the zone contains multiple links with different size of bandwidth, therefore, zone can provide average performances (bandwidth and throughput) where single link or node does not
- *macro-level (pin-point measurement)*: easy to collect the network information; this is because measurements are collected from the border routers only
- *user-friendly*: both technical and non-technical users can understand easily
- *geographical performances*: easy to monitor the flow information on the map based on geographical location.

But when the zone has no available bandwidth and more users require the zone what happened? Obviously congestion will occur at the zone. Congestion will occur when there is too much traffic in the zone. As mentioned earlier that a zone has a zone manager and border routers, all border routers of the zone have limited bandwidths. If a border router cannot transmit packets in a given instance (i.e., utilisation of the routers of the zone is high), it stores packet in the queue and waits for the next chance to transmit (i.e., packet transferred are delayed); as queue has limited size, if queue data exceeds limit, packet will be discarded from the zone. Therefore, if there is a mechanism that can save the packet from discarded from the zone, then this will be the best solution. Hence, ZBR algorithm for congestion control is necessary, which is responsible to overcome the zone congestion. As a result, the data will reach faster to the destination; packet loss probability tends to zero; at the peak hour, source zone can find alternate path to the destination, as the sender knows the path information before sending data. Hence, we can conclude that zone-based congestion control is appropriate for the user.

In this paper, we proposed a congestion control method based on the new concept of zone-based congestion control. In this method, zone manager collects QoS-related information (utilisation, throughput, bandwidth and delay) from the border routers to estimate the zone-level QoS (zone temperature and zone density) (Ahmed et al., 2004a, 2005). Zone temperature shows the utilisation of the zone, and zone density shows the service ability (available bandwidth) of zone. When the zone temperature and zone density are low, we call the zone is busy with traffic.

Therefore, traffic entering to the zone should be controlled, because it will result in congestion and long delays, or it will reject further traffic. So, by controlling zone temperature and zone density, we can control the congestion in zone level. We use the ZBR method to control zone-level QoS. ZBR is a routing method, which routes the traffic according to the states of zone (zone status) between source and destination. We will discuss ZBR method in details in subsection 4.1. Using ZBR, traffic will go through the zone that has average temperature and average zone density (i.e., congestion-free zone). As a result, users may feel good, but it will take time to find a zone that is free from congestion or users have to wait until the zone is free from congestion.

However, there is another method we apply to the zone, which makes the 'congested zone' into 'congestion-free zone'. We use the popular augmented algorithm to find an alternative zone to the destination (detail is given in subsection 4.2); as a result, a zone could be relieved from congestion. When the zone status is about to reach congestion, the zone manager will announce to its neighbouring zones to find an alternative zone to the destination. Therefore, a zone can protected from congestion.

The rest of the paper is organised as follows. In Section 2, we briefly review some related approaches of routing methods. In Section 3, we discuss the communication mechanism of zones. In Section 4, we present the zone-based congestion detection mechanism. In Section 5, we present zone-based congestion control method. In Section 6, we present our simulation model, results and analysis. In Section 7, we present the comparison among existing routing methods and protocols. And we finally conclude the paper in Section 8.

2 Related works

Many research works have been dealing with congestion control algorithms. Most of them start from extending the ability of current 'best-effort' routing algorithms. The widest-shortest path and the shortest-widest path (Braden et al., 1998) are variations of the shortest path algorithm. The widest-shortest path algorithm computes the shortest path, and if there is more than one shortest path, it chooses a path with maximum reservable bandwidth. The shortest-widest path chooses a path with maximum reservable bandwidth, and if there are several such paths, then the path with the lowest hop-count (shortest) among them is chosen. These algorithms do not take into consideration the links that often get congested in the network, and this leads to the imbalance in the network utilisation.

Minimum Interference Routing with Application (MIRA) to MPLS (Stevens, 2001) Traffic Engineering (Curran et al., 2002) is an online algorithm, which does not have any prior knowledge of the traffic requests. This algorithm chooses a path for the request that causes minimum interference for the future potential data flows. This algorithm focuses on reducing the interference on single ingress – egress pairs, and it does not find the bottlenecks in the network. So, this algorithm might choose a wastefully long path, although a more direct path with the required bandwidth exists. This algorithm is also computationally intensive.

Profile-Based Routing (PBR) (Suri et al., 2003) uses the 'traffic profile' of the network obtained by measurements or Service Level Agreements (SLA), as a rough predictor of the future traffic distribution. The paths are pre-computed in the pre-processing phase of the algorithm and are used in the online phase to switch the traffic.

Other related works (Ma and Steenkiste, 1997; Jain and Dovrolis, 2003; Jain, 1992; Sarkar and Tassiulas, 2002; Brakmo and Peterson, 1995; Ohsaki et al., 1995; Mishra et al., 1996; Floyd and Jacobson, 1995; Floyd and Fall, 1999; Oida, 2001; Narula-Tam and Modiani, 2000; Baumgartner and Wah, 1989) also proposed different types of algorithm for congestion control.

However, all the mentioned models have been proposed to control the congestion for a single network device (router, link, etc.), which is at micro-level. The main problems in micro-level are:

- when the link or the router between source and destination is highly congested, data cannot reach to the destination in expected time
- if any one of the link or router between source and destination is broken down, users have to wait for the mechanical solutions for the recovery, which will take long time
- before sending the data, users do not know whether the path between source and destination is ready to carry the data or not.

To fulfil these requirements, we propose zone-based congestion control method, which is macro-level. In macro-level communication, users do not have to wait to find whether the link or router is congested or in critical situation.

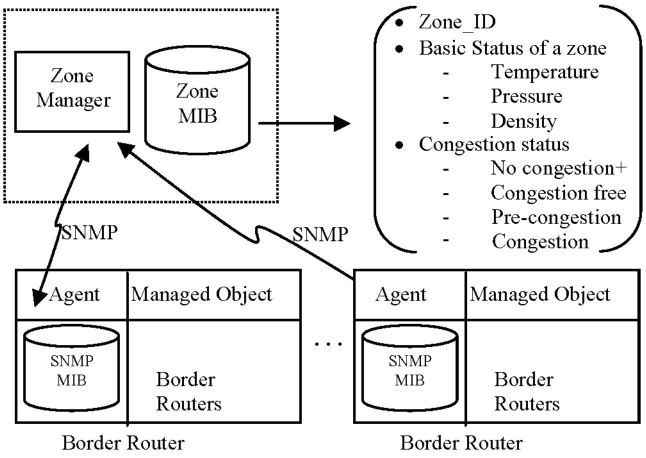
3 Zone-based communication mechanism

3.1 Communication among zone managers and border routers

The zone manager and border routers of the zone do communication in a zone. Zone manager is responsible to store information in a database (IRR-MIB) (www.irr.org) of all the border routers of the zone using Simple Network Management Protocol (Blumenthal and Wijnen, 1999) for border routers to send their information on traffic (throughput, utilisation, bandwidth and delay) to the manager. Each border router has its own database to store the parameters (incoming flow, outgoing flow, peak bandwidth, etc.). Then it sends them to the zone manager. Zone manager estimates the status of each border router and broadcasts them to all border routers of the zone.

Therefore, border routers can know the dynamic status of all border routers of the zone. The status of the zone is dynamic, because the information is updated in a period of time ‘*t*’. The period of time ‘*t*’ varies from zone to zone. Architecture of zone management system is shown in Figure 1.

Figure 1 Architecture of zone management systems

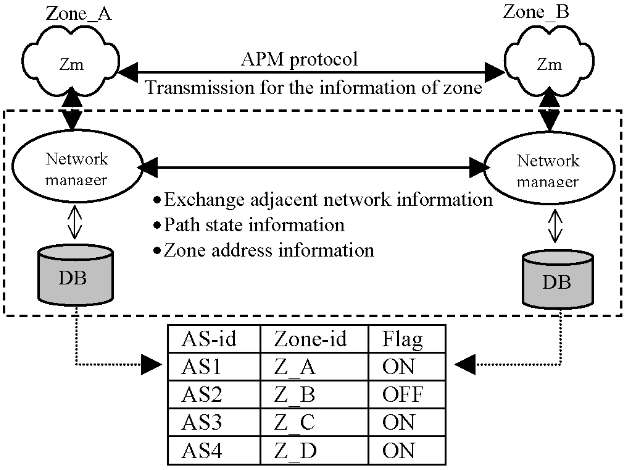


3.2 *Communication between different zones*

To communicate with different zones, we use Autonomous Path Management (APM) protocol (Tomomoto et al., 2001; Saito et al., 2002). APM is a path state protocol, by which the adjacent zone information is exchanged, such as zone ID and flag. Zone ID indicates the identity of zone in IP address, and flag indicates the connection status by ‘ON’ or ‘OFF’. By connection status, sender zone can know whether destination zone accepts the traffic from the sender zone or not. The adjacent zone information is advertised to the all zones in the internet called path state advertisement. Each zone accepts the path state advertisement. The collected information is used to calculate the routes to the target autonomously, and then optimum route can be selected flexibly from the calculated results.

APM network manager is able to store and advertise the path state information among zones. The information is zone address, zone parameters (temperature, pressure and density) and congestion level of the zone. Figure 2 shows communication between Zone_A and Zone_B, where both the zones have zone manager. Zone manager requests network manager of APM to make connection with target zone. Network manager finds the address of target zone from its database and then sends back to the requested zone manager with the address and the status of the zone. The status contains zone parameters (temperature, pressure and density) and congestion level (no congestion$^+$/congestion free/pre-congestion/congestion).

Figure 2 Communication between zones



AS-id	Zone-id	Flag
AS1	Z_A	ON
AS2	Z_B	OFF
AS3	Z_C	ON
AS4	Z_D	ON

Figure 3 shows the message sequence from border routers to zone manager of a zone, and Figure 4 shows the message sequence of zone manager to neighbouring zone managers with the following phases.

Figure 3 Message sequence between border router and zone manager

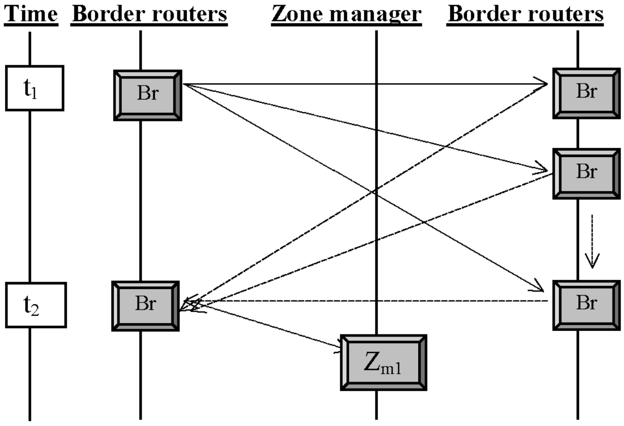
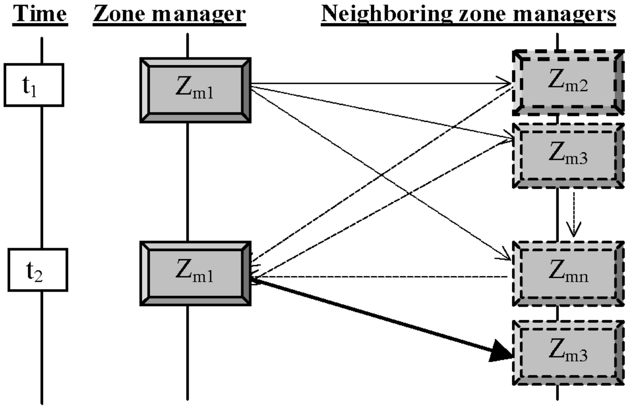


Figure 4 Message sequence between zone managers



At time t_1. In phase-I, border routers do the two tasks:

- send message to other border routers of the same zone
- collect throughput, utilisation and bandwidth of each link (input and output).

In phase-II, border routers receive the throughput, utilisation, bandwidth and delay from requested border routers and links. In phase-III, border routers compute the average throughput, utilisation, bandwidth and delay. In phase-IV, border routers send throughput, utilisation, bandwidth and delay to the zone manager. In phase-V, zone managers receive throughput, utilisation, bandwidth and delay. In phase-VI, the zone manager computes zone parameters (temperature, pressure and density) using our proposed mathematical equations, presented in Ahmed et al. (2004b). And based on temperature and density, level of congestion is estimated. In phase-VII, the zone manager requests target zones for the congestion status and receives the response, and finally, in phase-VIII, the zone manager selects appropriate zone and communicates with it. In this way, 'border routers and zone manager' and 'zone manager and zone manager' communicate with each other by exchanging information periodically.

3.3 Zone-based communication method

To compute the zone parameters (temperature, pressure and density) and congestion status (no congestion$^+$, congestion free, pre-congestion and congestion) dynamically, zone manager collects the low-level parameters such as throughput in bps and delay in msec from the border routers of the zone. Throughput is a standard network transmission capability, which indicates how much traffic has been transmitted in unit time. The throughput of a border router equals the average throughput of all links (input and output) of the router, and the throughput of a zone equals the average throughput of border routers of the same zone. In the case of zone delay, each border router measures the delay to other border routers of the zone and then sends the average to zone manager. Then zone manager estimated the average delay, which we call zone delay. To compute the zone parameters, border routers and zone managers do as follows:

- each of border routers collects ping delay to each of other border routers of the same zone and collects throughput of all links (input and output) of the router
- each of border routers computes its average delay to all other border routers in the same zone and average throughput of all links of the routers based on formula
- each of border routers sends the average delay and the average throughput to the zone manager
- the zone manager receives the throughput and the delay from all border routers of the zone periodically
- the zone manager computes the zone parameters (temperature, pressure and density) and congestion level based on formula
- the zone manager requests target zone for zone status
- the zone manager selects target zone for transmission.

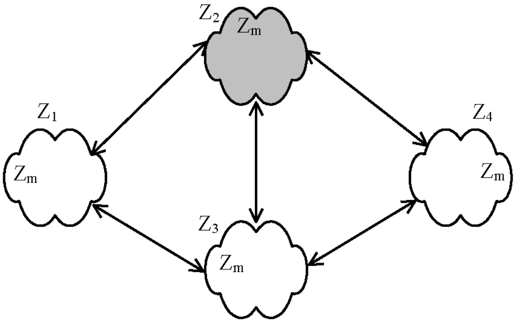
4 Zone-based congestion detection

The problem of routing is to optimise flow of packets through a zone with various constraints such as

- optimise zone utilisation
- minimise cost of switching
- minimise the number of hop counts
- optimise the use of zone bandwidth.

The basic problem of routing through links is equivalent to the max-flow or shortest path problem and can be solved in polynomial time. No routing research has been done yet over the zone. A new algorithm called the ZBR algorithm is proposed for solving the zone congestion. Example: In Figure 5, zones (Z_1–Z_4) are the resources. Zone Z_1 wants to send data to the destination zone Z_4 through any one of Z_2 or Z_3. Each of these zones has a different state. Let the state of Z_2 be red and Z_3 be green.

Figure 5 Example of routing policy



Therefore, Z_1 uses Z_3 for the faster transmission. In Figure 5, grey colour indicates the zone has low temperature and low density (Z_2 in Figure 5), and white colour indicates the zone has high temperature and average density (Z_3 in Figure 5). But how do we know the state of its neighbouring zones Z_2 and Z_3? In the following, we explain about the state of the zone.

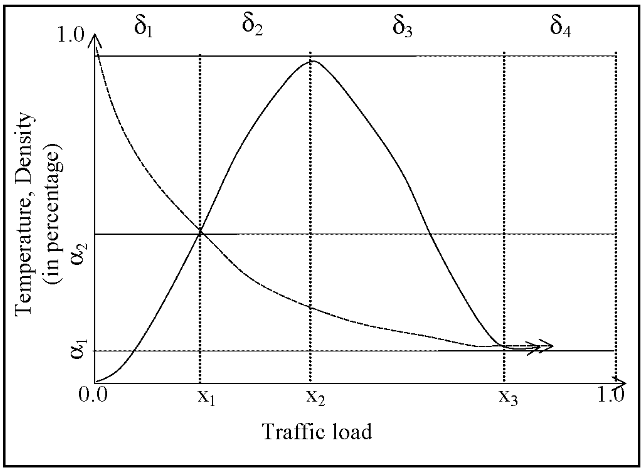
In Figure 6, the solid-line curve shows the temperature, and the dotted-line curve shows the density of the zone. Horizontal axis shows the traffic load, and vertical axis shows the temperature and density of the zone in percentage.

We define four types of zone states:

- no congestion $^{(+)}$ (δ_1)
- congestion free (δ_2)
- pre-congestion (δ_3)
- congestion (δ_4).

In Figure 6, when the traffic load is in the range of 0.0 to x_1, temperature and density is greater than α_2; in this situation, zone requires more traffic and the zone status is 'No Congestion $^{(+)}$'. When the traffic load is between x_1 and x_2, temperature increases up to the maximum capacity of the zone and density is little low, which is greater than α_1 and less than α_2; in this situation, applications use maximum capacity of the zone and the state is 'congestion free'. In the case of traffic load in between x_2 and x_3, temperature is slowly decreasing and density is slowing down, so delay will be little high and the state is 'pre-congestion'. Therefore, application cannot inject traffic, because it will result the zone congestion. Finally, when the traffic load is in the range of (x_3, 1.0), zone is at congestion level, because temperature and density is very low, which means less than α_1, therefore, to use this zone will take long delay and no traffic can enter in this situation.

Figure 6 Zone-based congestion detection



Congestion in a zone is loosely defined as a condition where demand for resources (usually density of zone) exceeds capacity.

Example: Let the capacity of the zone be 50 Mbps and let two processes use this capacity, if other processes require the same zone at the same time, meaning the demand for zone exceeds the capacity. Much research has been proposed to control the congestion for network (router, link, etc.). Presently, congestion control tries to prevent demand from exceeding capacity (Suri et al., 2003). It is possible for a zone to contribute to control congestions by the following strategy:

- the zone must be able to signal the neighbouring zones that congestion is occurring (or about to occur)
- the neighbouring zones must have a policy that decreases zone temperature if this signal is received and increases the temperature if the signal is not received.

Therefore, all zones can select a suitable zone from their neighbouring zones to transmit data.

4.1 Zone-Based Routing (ZBR)

If all the resources (zones) have their own zone manager and all managers can negotiate with their neighbouring zones to know the zone-state, then the source zone can send the data to the zone, which has the state with 'no congestion'. In ZBR, there may be a single or multiple neighbouring zones that have the same state. For the single neighbouring zone whose state is 'no congestion', the source zone will send its message to it. On the other hand, for multiple neighbouring zones with the same state, the source will apply the well-known Dijkstra's algorithm to find the appropriate path to every other zone. The ZBR has the following method to send the data. The idea behind ZBR is simple and can be stated as follows. Each zone must.

- discover its neighbours and learn their status (indices: zone temperature and density)
- select the appropriate index to each of its neighbours
- involve routing (Forwarding [diffserv]).

Each zone manager will discover the end-to-end states between a source and its destination by the following equation:

$$\text{State}_{s2d} = aR + bY + cG \tag{1}$$

where

a: number of red zone
R: $\alpha \times \varphi(T, D)$
b: number of yellow zone
Y: $\beta \times \varphi(T, D)$
c: number of green zone
G: $\gamma \times \varphi(T, D)$.

Assume that $G = 1$, $Y = 2$ and $R = 3$. If a virtual path from source zone to destination zone has one red zone, two yellow zones and one green zone, then by the above equation, we can calculate the state, which equals 8. Again, if a virtual path has two red zones and one green zone, where the state equals 7, then from the above two, the source zone will select the second route to send the data. Also, source zone considers the number of hops from source to destination, as each transit zone has a processing delay, therefore, if the state of the source to destination is same but the number of hops may vary. So, the sender selects the minimum number of hops. By using the dynamic zone-based routing, zone-based congestion control will be able to achieve efficient zone utilisation. However, this idea will be more realistic if it is possible to avoid the zones congestion, which means that red zones become yellow or green. To avoid the zone congestion, zone managers will negotiate with its neighbouring zones to find out the available zone (zone with high temperature), which means that if a zone state is with a low temperature and some users try to use the same zone, then the temperature will decrease remarkably and no users can use the zone. To overcome this problem, we propose selecting the zone using the popular augmenting path selection algorithm in the next section.

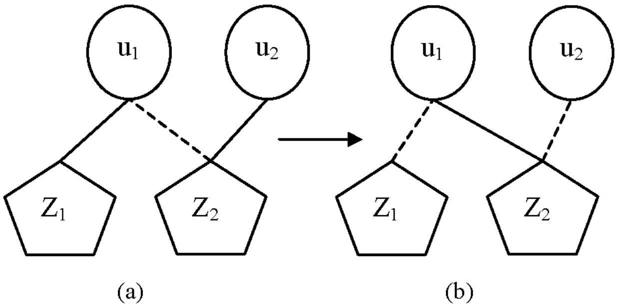
4.2 Augmenting path selection

In the case of users requiring the low-temperature and low-density zone cannot be used at the same time, or if one user acquires the zone, it will become congested; therefore, negotiation is required.

The negotiation is played through the zone managers required by the users. Then, the available zone (high-density zone) is transferred from one user to another user, and finally, more users can use different zones.

Negotiation is based on the idea of augmenting paths in a bipartite graph, the two subsets of which are the set of users and the set of zone managers, respectively. Figure 7 shows a simple example of negotiation. We use an example to explain our basic ideas. In Figure 7(a), suppose u_1 has two acceptable zones Z_1 and Z_2, and u_2 only desires Z_2. It is assumed that Z_2 has been allocated to u_1. If u_1 can release the allocated Z_2 and tries to acquire and use Z_1, then u_1 and u_2 can acquire Z_1 and Z_2, respectively as shown in Figure 7(b); therefore, the requirements of both users are satisfied. The augmenting path searching algorithm will search the zone until it finds out the respected zone from the whole zones.

Figure 7 Example of negotiation between zones



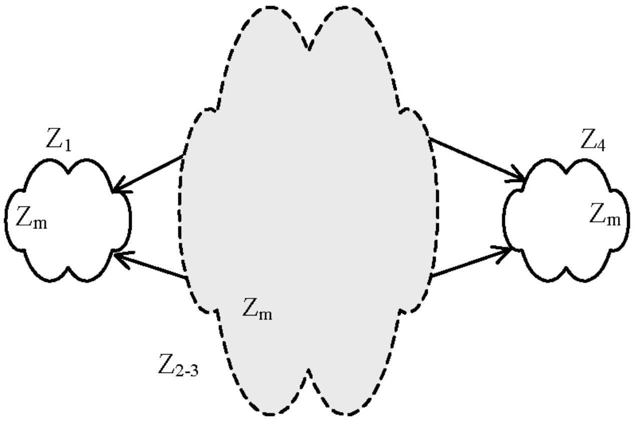
5 Zone-based congestion control

In a distributed communication systems, load-balancing method provides available density of the zone. Density reflects how available the zone is. Once, the zone has no availability (low density), which means no other zone can use it to transmit flow. In this situation, load-balancing method is needed to create the zone high density. Here, we use an example to describe a Zone-Based Load-Balancing (ZNLB) method.

Consider a network as a set of zones Z, where each zone Z_i ($i = 1, 2, \ldots, n$) belonging to Z has a temperature T^z_i ($i = \beta_1, \beta_2, \beta_3, \beta_4$) and density D^z_j ($j = \Gamma_1, \Gamma_2, \Gamma_3, \Gamma_4$) that is greater than zero. For example, in Figure 8 in subsection 5.1, if source zone Z_1 wants to send data to the destination zone Z_4, it has to go through any one of the transit zones Z_2 or Z_3. And these two transit zones are with high temperature and average density, and average temperature and low density, respectively, which means one of them is congested and other one is pre-congested. In this situation, one possible solution is that Z_1 has to wait until any of the transit zones become a high temperature and density, which may take a long time, even if, suppose, two neighbouring zones have the available bandwidth.

More specifically, Z_2 and Z_3 have a bandwidth of 20 Mbps and 21 Mbps, respectively, where maximum bandwidths of 22 Mbps and 24 Mbps are used. In this situation, if Z_1 wants to send 5 Mbps data, neither Z_2 nor Z_3 can permit the data to transit to destination Z_4. As a result, the rest of the bandwidths ($2 + 3 = 5$ Mbps) are unused. So, if there were some method that can combine these two transit zones into one, then the Z_1 could send its data and the unused bandwidths of Z_2 and Z_3 could be used. To overcome the above-mentioned problem, we propose a new solution called a zone-based load-balancing (ZBLB) method, which will make the zone congestion free and use the wasted bandwidths. Finally, users will find high density of zones, which ensure that quality of services (low delay and high throughput) is good for data transmission.

Figure 8 Example of zone-based load balancing



5.1 Proposed load-balancing method

ZBLB is designed to provide available zone of communication ability to transmit flow. It is a new method, which is based on ZBR algorithm.

From the Figure 5 in Section 4, we suppose that zone Z_1 has only one neighbouring zone Z_3, which has average density (i.e., zone state is δ_3). Let Z_2 be announced first for the 'no congestion$^{(+)}$ or congestion free' zone. Therefore, Z_3 will Acknowledge (ACK) Z_2 to be combined. Hence, Z_2 and Z_3 will combine together to make the zone balance, which means that the state of the combined zone $Z_{2\text{–}3}$ (in Figure 8) will be δ_3. Hence, zone Z_1 is able to send data to Z_4 through the combined transit zone $Z_{2\text{–}3}$. Thus, our proposed method is fit for balance of traffic load to ensure that each zone has at least one high-density neighbouring zone.

5.2 Conditions to combining and separating zones

When the density of a zone becomes low, it needs to be combined with other zone. Two types of zones can combine together: 'pre-congestion or congestion' zone and 'no congestion$^{(+)}$ or congestion-free' zone. The zones, which need to be combined, are called 'pre-congestion or congestion' zones, and the zones, which help by joining with 'pre-congestion or congestion' zones, are called 'no congestion$^{(+)}$ or congestion-free' zones. Before combining zones together, the following conditions are necessary:

- all 'no congestion$^{(+)}$ or congestion-free' zones agree to combine with their neighbouring 'pre-congestion or congestion' zones
- if the state of the zone is δ_4 (we call it a 'pre-congestion or congestion' zone), it will announce its intention to be combined
- the zone will not allow data to be received when it is at the 'δ_3' state
- after a certain time, if the combined zone finds there is more than one neighbouring zones in the table, whose states are δ_3, it will then divide again to individual zones (example: combined zone $Z_{2\text{–}3}$ will go back to its default mode as 'zone Z_2' and 'zone Z_3').

5.3 Estimations to combining zones

In Section 3, we have described how to collect zone-based low-level parameters to estimate the zone temperature and density. Here, we explain how to collect combined-zone parameters (low-level parameters). For a single zone, Z_2 collects the low-level parameters (throughput and delay) from its border routers (assume that the border routers are $Z_{2\text{–}r1}$, $Z_{2\text{–}r2}$, $Z_{2\text{–}r3}$ and $Z_{2\text{–}r4}$), and Z_3 collects the low-level parameters (throughput and delay) from its border routers (assume that the border routers are $Z_{3\text{–}r1}$, $Z_{3\text{–}r2}$, $Z_{3\text{–}r3}$ and $Z_{3\text{–}r4}$).

Now, let Z_2 and Z_3 be combined with new name $Z_{2\text{–}3}$. In this case, the nearest border routers of zone Z_2 and zone Z_3 are $Z_{2\text{–}r4}$ and $Z_{3\text{–}r4}$, which are not considered as one of the border routers; therefore, the zone manager of the requested zone Z_3 will collect the low-level parameters from the border routers $Z_{2\text{–}r1}$, $Z_{2\text{–}r2}$, $Z_{2\text{–}r3}$, $Z_{3\text{–}r1}$, $Z_{3\text{–}r2}$ and $Z_{3\text{–}r3}$, respectively, to estimate the temperature and density of the zone $Z_{2\text{–}3}$. (We name the new zone $Z_{2\text{–}3}$, because other zones can recognise which zones are combined. The first suffix indicates the 'pre-congestion or congestion' zone, and after the dash, the second suffix indicates the 'no congestion$^{(+)}$ or congestion-free' zone). When sending data to the transit zones, the 'pre-congestion or congestion' zone must do the following:

- read a neighbouring state table from the routing table
- announce to the neighbouring 'no congestion$^{(+)}$ or congestion-free' zones it is 'pre-congestion or congestion'
- receive the zone ID with 'no congestion$^{(+)}$ or congestion free'
- select one randomly or select First ACK First Combined (FAFC) if there is more than one ACK
- when combined, the routing table will update the registry with the new names of the combined zone; i.e., change the mode for collection of data from single mode to group mode
- send traffic/data.

5.4 Pros and cons of combining and separating zones

- All zones find the available zone to transmit flow.
- The operation of combination and division of the zone is applied for multiple zones in which the route exists for them.
- By combining zones, congested zone becomes congestion free, and QoS is improved.

By the separation of zones, load balancing is controlled. It will take time to combine zones and separate zones when other neighbouring zones will have available bandwidth.

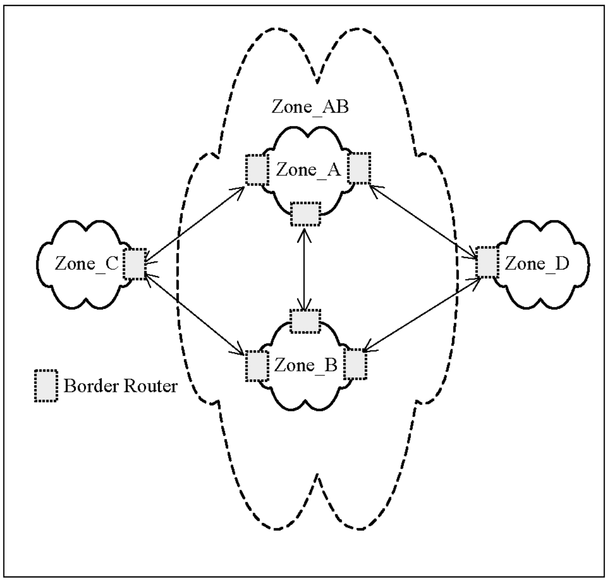
6 Simulation model, results and analysis

In order to show the zone metrics such a way, which can enables users to grasp the zone status intuitively, we performed a simulation. In this section, we obtained the obtained results from the simulation. Based on the results, in the next subsection, we analyse that a combined zone can provide better service comparing to a single zone. Better service indicates the zone with no congestion.

6.1 Simulation model

In this section, we verify our proposed zone-based load-balancing method. Figure 9 shows an example of our simulation. In the simulation model, we set four equal capacities of zones (Zone_A, Zone_B, Zone_C and Zone_D) to generate the flows. All zones have border routers, where traffic/data are coming in and going out through these routers.

Figure 9 Simulation model

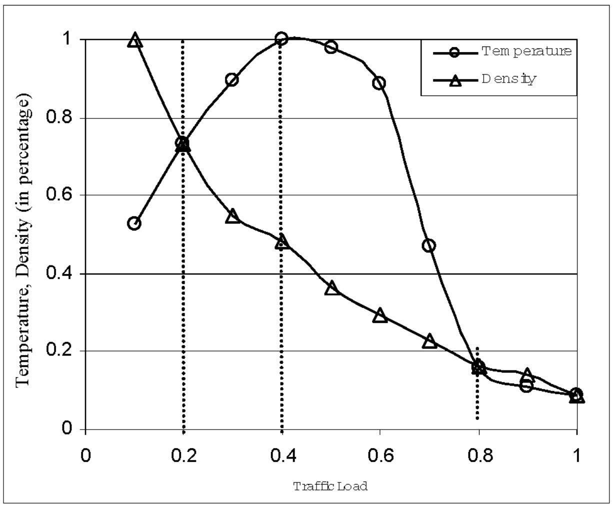


In Figure 9, we have considered, Zone_C is a sender and Zone_D is a receiver. Zone_A and Zone_B are the transit zones between sender and receiver. Zone_C can use any one of the transit zones. When these zones are with very low density, it is hard to transit traffic, results, it will take long time. Therefore, we combined the two transit zones into one, which we call Zone_AB. Then, we send traffic from each zone to others and obtained the results. The results are analysed in the next section.

6.2 *Explanation of simulation results and discussion*

In Figure 10, we show the results of the zone congestion (in percentage) compared with the different values of zone temperature (in percentage) and zone density (in percentage) by the amount of traffic load.

Figure 10 Analysis of zone-based congestion detection comparing with temperature and density by the amount of traffic load

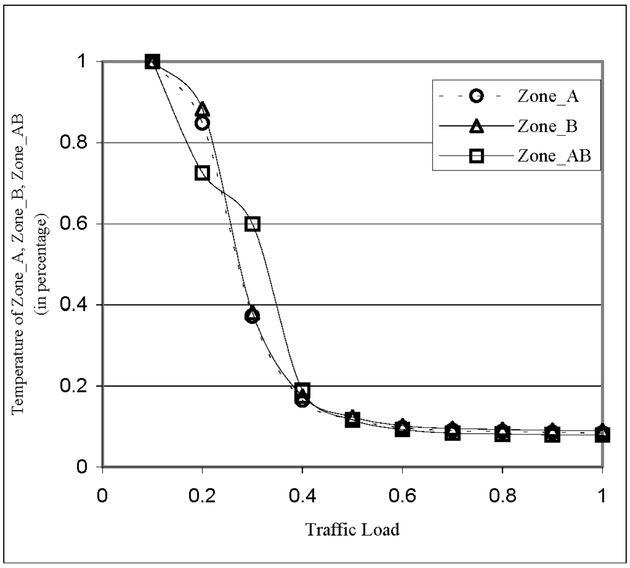


As shown in the figure,

- When the traffic load is in the range of (0.0, 0.2), temperature is low, density is high and the zone state is no congestion(+); therefore, in this situation applications require more throughput.
- When the traffic load is in the range of (0.2, 0.4), temperature is increased and density is little slow, and zone-state is congestion free; therefore, applications are using maximum capacity of the zone.
- When the traffic load is in the range of (0.4, 0.8), temperature is slowly decreasing and density is slowing down, so the state of zone is pre congestion; therefore, application cannot inject traffic because it will result the zone congestion.
- When the traffic load is in the range of (0.8, 1.0), zone is at congestion level, no traffic can enter this situation because it may reject further traffic. As a whole, users demand a 'No congestion(+)' or congestion free zone. Comparatively, congestion free is reached when the zone is less busy.

In Figure 11, we show the results of the combined zone compared with the temperature of two single zones (in percentage) by the amount of traffic load.

Figure 11 Temperature analysis of combined zone comparing with single zones by the amount of traffic load



As shown in the figure, when the traffic load is at 0.3, the temperature of both the single zones, Zone_A and Zone_B, is less than 0.4; on the other hand, after combining these two zones, the temperature of Zone_AB is 0.6, which is greater than the single zones. Therefore, traffic load at 0.3, combined zone can offer more traffic where single zones cannot. As a whole, users demand a higher temperature zone. High temperature is reached when the zone is less busy.

In Figure 12, we show the relation between single zones with the combined zone in five different cases. In the case of one, Zone_A is with 10% traffic load and maximum temperature, and Zone_B is with the 100% traffic load where temperature is 0.79 in the Figure 12. As shown in the figure, after combining the Zone_A and Zone_B, the temperature of Zone_AB is 0.53, which is greater than Zone_A. Similarly, we have shown the results of combined zone and single zones in other four cases, which give an idea for selecting the types of zone to be combined.

Table 1 represents the temperature data of two single zones and a combined zone. 'Temp' indicates the temperature, and 'TL' indicates the traffic load. In the table, we show the relations of temperature in three different cases of two single zones and a combined zone.

Figure 12 Temperature analysis of combined zone comparing with single zones by different cases

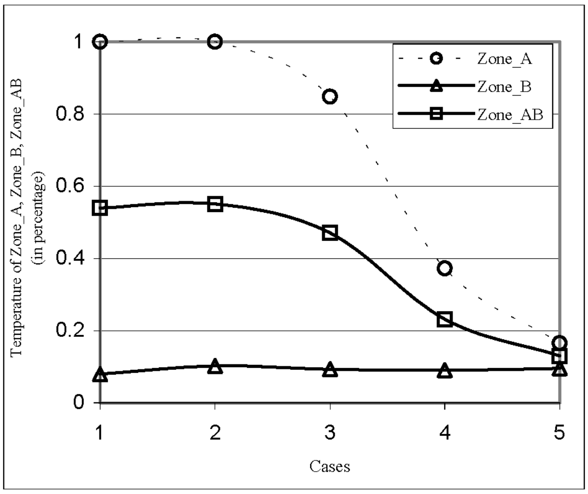


Table 1 Temperature data in three different cases

Zone Temp/TL	*Zone_A Temp/TL*	*Zone_B Temp/TL*	*Zone_AB Temp*
Case 1	1.000/0.1	0.102/0.1	0.551
Case 2	0.372/0.3	0.090/0.3	0.231
Case 3	0.165/0.4	0.095/0.4	0.130

7 Comparison

7.1 Comparison with existing algorithms

Shortest Path Routing (SPF), Widest-shortest Path Routing (WSP), Minimum Interface Routing (MIRA) and PBR do not have the scalability, as they monitor the congestion at micro-level and they detect the congestion after congestion happens. On the other hand, ZBR is at macro-level and is an early congestion detection mechanism. Therefore, no congestion will happen throughout the internet communication, since zone manager will take necessary actions when the zone status towards an alarming level. The alarming level is when the zone goes down to the critical situation by receiving further traffic load.

In the SPF, it chooses the least number of links between source and destination. The routing algorithm keeps the current residual capacity of those links. The algorithm is simple, but it can create bottleneck for future traffic.

WSP chooses the minimum hop with largest bandwidth; it discourages the use of heavily loaded links. It also selects the path as SPF does. Therefore, network will reach at critical situation, where no traffic can enter at that time.

MIRA is based on the observation that usage of certain critical links must be avoided to the extent possible. It does not consider the traffic asymmetries, which result from certain source – destination pairs having more offered traffic. Also, it does not permit the protection of certain source – destination pairs from having the available capacities being reduced too much by traffic traversing between other source – destination pairs.

PBR attempts dynamic routing for guaranteed bandwidth of path between source and destination. Using this algorithm, users can share the available bandwidth without rejection requests, but throughput is very low. Even if users need high bandwidth in case of emergency, this algorithm fails to fulfil users demand.

However, our proposed algorithm, 'ZBR', is simple and computationally efficient as SPF. It shows the results on map, which is easy to understand, where others show in text based. It never rejects request from users. It provides minimum delay and optimum network utilisation; ZBR improves the quality of network, as the flow can reach smoothly (without congestion) to the destination. Table 2 shows the comparison with existing algorithms vs. our proposed ZBR.

Table 2 Comparison with existing algorithms

Algorithms	*Scalability*	*Congestion detection*	*Output*	*Results*
SPF	Micro	After congestion	Text	Low delay
WSP	Micro	After congestion	Text	High BW
MIRA	Micro	After congestion	Text	High throughput
PBR	Micro	After congestion	Text	Guaranteed BW
ZBR	Macro	Before congestion	Map	No congestion

7.2 Comparison with existing zone protocols

Haas and Pearlman (1997) proposed a hybrid proactive/on demand routing scheme called Zone Routing Protocol (ZRP). In ZRP, each node proactively maintains the topological information within its routing zone only. ZRP exploits the structure of the routing zone through a process, which is called bordercasting. Bordercasting allows a node to send messages to its peripheral nodes (nodes on the boundary of its routing zone) and prevents non-peripheral nodes from accessing the messages.

Joa-Ng and Lu (1999) proposed Zone-based Hierarchical Link State (ZHLS), which is a hierarchical reactive/proactive routing protocol. It incorporates location information of peer-to-peer routing. Each node knows its position and zone identity through GPS. Source zone forwards its packet by specifying the zone identity and node identity in the packet header. The topological information is distributed to all nodes in peer-to-peer manner. This peer-to-peer characteristic avoids traffic bottleneck, prevents single point of failure and simplifies mobility management.

Pei et al. (2000) proposed Fisheye State Routing (FSR), which is a hierarchical routing protocol. It is functionally similar to link state routing, which maintains a topology map at each node. The main difference is the routing information is disseminated. The reduction of routing update overhead in FSR is obtained by using different exchange periods for different entries in routing table. FSR produces timely updates from near stations but create large latencies from stations afar.

ZBR is a hierarchical routing scheme. Using ZBR, a zone manager can route its traffic to the destination effectively and efficiently. When sender zone manager sends its traffic, it must select the zone in which congestion ratio is less than 1. Since zone managers can communicate with each other, therefore, it is easy to know the level of congestion of the target zone. If the congestion ratio of the target zone is less than 1, sender zone then selects the zone to sends its traffic. If there are multiple zones in the same level of congestion ratio, sender zone will select one randomly.

GRP, ZHLS and FRS protocols are proposed for routing in wireless networks. Our proposed routing protocol, ZBR, is for wired network. To select the end-to-end route, ZRP searches the route by sending a route query packet from source node to the destination and waits for the reply from the destination. Using ZRP, ZHLS and FRS protocols, all source nodes must have to know the routing information. But using ZBR, only zone manager keeps the routing information to forward the traffic. Therefore, if a border node is enough to carry traffic than all sender sources may send their traffic to that border nodes, as a result, traffic may exceed the capacity of the border node and become congested. On the other hand using ZBR, zone manager selects the border node with distributed manner, where a border node can prevent from congestion.

Table 3 shows the comparison with existing dynamic routings with our proposed ZBR for congestion control.

Table 3 Comparison with existing zone protocols

Protocols	*Search route*	*Routing maintenance*	*Routing information*
ZRP	From source to destination	By node	Node state
ZHLS	From source to destination	By node	Node state
FSR	From source to destination	By node	Link state
ZBR	From source (zone DB)	By zone manager	Zone status

8 Conclusion and future work

In this document, we have shown how to detect the level of congestion of a zone. Current internet traffic flows are routed by the estimated value of a single network device, i.e., a router or a link between two nodes. The ZBR algorithm considers multiple routers and multiple links to estimate the strength of the zone-activity to route the traffic. We also have proposed a new method for zone-based load balancing. Zone-based load balancing can minimise the internet traffic congestion. Load balancing provides low delay, high throughput and high bandwidth availability, which ensure that zone-based load balancing can minimise the zone congestion. Some future works are summarised as follows: zone-based peer-to-peer networking (Distance Learning, Video Conferencing, etc.). Show zone-based congestion states on the zone map.

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