traces are filtered after minimal hop count per protocol representing the minimal path length. Every hop causes a probabilistic delay through processing, which we can only be estimated. Thus, our focus is to keep the impact low. Of each used protocol, we select the maximum value to obtain the truthful number of network nodes on the path. The small time and hop deviation of asymmetric connections are balanced by using minimal RTT and the adaptive model construction with predefined, static delay overheads and the self-tuning *LC* factor. The minimum delay and hop deviation in comparison to the real path is balanced with the adaptive model construction and self-tuning *LC* factor.

5. Evaluation and Assessment

In order to verify our concept and algorithm, we set up multiple experiments. As our focus is Europe including private users with moderate internet connections via DSL, we use public available information and research data from the TIER 1 topology like [14]. We have to build a set of distributed reference hosts to which we have access to. For this purpose we are using the RIPE Atlas Project [18] providing us with over 8200 possible well-known nodes for probing. RIPE Atlas provides a comprehensive distributing of nodes in terms of different bandwidth and population density. Thus, for Europe we are not limited to residential areas only.
The first step is to calculate optimal positions in respect to the given topology. Afterwards we compare these locations to our set of reference hosts to find direct matches or nearby nodes according to latitude and longitude. The next steps follow exactly our presented model in Section 3. To determine the hop count and the RTT we use Traceroute, Paris Traceroute, and ICMP echo request provided by the RIPE Atlas measurement interface. By using the hop count and the measured minimum delay out of ten measurements, a logarithmic curve is calculated in order to represent a correlation between measured latency and road network distance. The Latency-Distance-Curve reconstruction is calculated parameter pairwise iteratively with the tool R and the curve fitting method *nls*. After probing the target IP address from each Landmark, the curve is used to convert the RTT and hop count to a geographic distance. Using the calculated distance as well as the knowledge of longitude and latitude of each probing Landmark, Dragoon is able to infer the location of the target.

Result 1: For a suitable measuring method, we evaluate the influence of the packet size on the latency. Figure 14 compare the latency of the minimum packet size with the almost maximum packet size avoiding packet fragmentation. The time period is about 30 days whereas every measurement point represent the average delay within one hour for a large sample set of communications in Europe, using the minimum delay for each communication. The influence is negligible as long as the no packet fragmentation is mandatory.

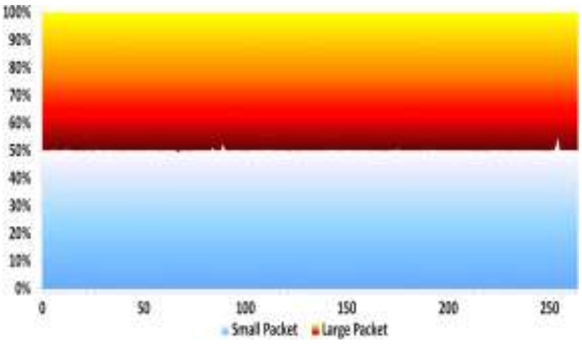

Figure 14. Delay difference between small and large packets

Result 2: For an improved target estimation, we analyse the average latency distribution during a long time horizon. Such an aspect influences the Latency-Distance-Curve and the calculated distances based on the latency. Figure 15 shows the latency distribution for 30 days, whereas every measurement point represent the average delay within one hour, using the minimum delay for each communication. The delay is almost the same and independent from day time as well as week days. There are some outliers which are hard to predict. Especially the red marked pillars results from a Microsoft Security Bulletin and Patch Day. To counter such effects, the self-tuning *LC* factor is necessary. All measurements should be applied in a short period of time to have similar conditions and to obtain a suitable reference RTT.

Figure 15. Average delay over 28 days between Landmarks

Result 3: The Table 1 shows an excerpt from the comparison of estimated target locations obtained by different applied Landmarks, which are identified by Dragoon and 2-Approx. Since the used scenario is too large for common ILP solver, we used the alternative algorithm 2-Approx. It illustrates the impact of the selected Landmarks to the results of IP Geolocation.

The comparison of the Latency-Distance-Curve based on GoogleMaps and orthodromic distance shows the difference in the curvature. The function using orthodromic distances is more curved and visualizes the impact of the "Last Mile"', which is to a limited extent covered by the modelling. For this reason and because of improved and more stable location estimation, the further calculations are based on the curve using Google Maps.

As we know that the logarithmic curve is too optimistic, we first identify a uniform *LC* factor to counter it and to analyze the model. For the curve based on Landmarks optimized by Dragoon, the *LC* factor is about *0.7* for distances obtained by Google Maps (GM) and Orthodroms (OD). This means the distance to a given Latency is 30% to large. For the function based on Landmarks identified by the reference algorithms, the optimized *LC* factor is *0.9*. With an self-optimized factor per target, we are able to achieve more precise results (see Table 2). This justifies our assumption that the Landmark selection and the reference distances have a strong influence on the result.

Table 1. Example comparison of the derivation between the location estimation to the real geographic location using different Landmark sets

Target	Dragoon (GM)	Dragoon (OD)	Reference Algorithm
1	120 km	117 km	350 km
2	136 km	536 km	1600 km
3	221 km	108 km	113 km

Result 4: The influence of the amount of Landmarks on the accuracy of the results is analyzed by two different data sets. We determined 17 target locations with the amount of 20 and 30 Landmarks, whereas the Landmark positions are independently optimized with our algorithm Dragoon. Table 2 compares the accuracy of the target determination for several IP addresses and their location. It shows the precision of our approach. The accuracy does not increase with the amount of Landmarks. Even if the results get more stable in relation to the variation of the parameter in our model, it is more important to reach accurate measurement results. Also the selection and accumulation of the right input data has a highly impact on the target estimation. Filtering through the model is only to counter measurement fluctuation. With a higher amount of Landmarks, the point cloud contains more possible locations, which are tougher to filter and to detect outliers. About 41% of the targets are localized within 50 km. More than the half of the results have a deviation of less than 100 km for only 20 Landmarks covering entire Europe.

Result 5: As other publications does not respect the special case of overlapping circles during lateration like illustrated in Figure 7, we evaluate the influence of this aspect in our model and the deviation of the determined target locations. Ignoring overlapping circles result in about 11% higher deviation as our modeling approach. Also the abstraction to the midpoint of the inner circle result in about 7% higher inaccuracy.

Result 6: Since active measurements have always been considered to be more precise as passive IP mapping-based techniques, we compared our approach to the passive services of MaxMinds [19] and WhoIs [5] as well as the active techniques Spotter [6] and TULIP [20] of the Stanford University (CBG, ACBG, Geoplugin and FreeGeoIP). This measurement shows the precision of our entire concept in relation to other state of the art techniques for example [13, 21].

As shown in Table 3. Dragoon is outperforming Whois by 67.21% with over 275km less average deviation. Interesting is, that MaxMind performs even worse than Whois with 70.96% and over 328.36 km average deviation. Also the other active measurement techniques show a large deviation for our targets. Since their approaches are not available for a direct comparison for single targets, we use the online service TULIP. It provides different re-implementations of these state of the art techniques and queries geodatabases. In contrast, our active approach respects the fluctuation of network delays as mentioned in result 2. It uses a more accurate estimation of network distances by road networks and improved placement of Landmarks. Additionally, the new model takes the hop count of the network path into account as well as further aspects as described in Section 4.

Table 2. Comparison of the derivation in km between the location estimation to the real geographic location using different amounts of Landmarks

Target	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Avg.
20 LM	0	3	11	23	28	38	43	87	95	148	176	194	205	268	268	307	390	134
30 LM	214	77	198	87	169	70	165	143	353	135	198	243	207	155	107	222	277	178

Table 3. Comparison of Dragoon with 20 Landmarks to active (non-italic) and passive (italic) IP Geolocation services

Target	Dragoon	*WhoIs*	*MaxMind*	Spooter	CBG	ACBG	Geoplugin	FreeGeoIP
1	0	*14*	*1*	478	481	481	1	1
2	3	*24*	*2*	193	179	179	2	2
3	11	*1*	*64*	221	109	109	64	64
4	23	*14*	*13*	738	806	795	13	22
5	28	*15*	*2*	6765	6765	6765	6765	6765
6	38	*12*	*2*	335	459	459	2	2
7	43	*379*	*370*	136	101	101	366	366
8	87	*453*	*381*	567	676	771	382	382
9	95	*16*	*65*	495	205	205	65	65
10	148	*24*	*3*	475	586	586	3	3
11	176	*433*	*477*	411	483	483	485	485
12	194	*69*	*402*	951	1063	1015	396	396
13	205	*5481*	*5474*	477	172	163	5390	5389
14	268	*2*	*341*	401	866	866	347	347
15	268	*1*	*13*	46	46	46	13	6
16	307	*28*	*254*	11	64	64	6	254
17	390	*0*	*1*	111	4	4	1	1
Avg. Deviation	**134**	***410***	***463***	**754**	**768**	**770**	**841**	**856**

6. Limitations and Discussion

If the rough underlying infrastructure is unknown, a determination of Center Nodes is not possible. Also helix like infrastructures will result in suboptimal calculations, hence more coarse-grained location estimations. Our approach obtains only precise results for targets located in the bounding box created by the Landmarks. Since it has to be assumed that at least the TIER 3 infrastructure provides in comparison to TIER 1 less capacity and connectivity, the logarithmic curve based on the TIER 1 infrastructure has to be considered optimistic. To overcome these shortcomings a more comprehensive knowledge of the TIER 1 to 3 infrastructure, the "Last Mile" as well as the transmission medium and the network load of different components is needed. Thus, the amount of Landmarks needed for probing is highly depending on that knowledge. Further factors which may have influence on the location estimation are the used protocol for probing. Traceroutes can be done by different protocols and algorithms, hence causing more or less overhead while different processing steps on the packet path. Caused by its design IPv6 may have impact on the measurements results, too. For moderate connected areas the knowledge of the used transmission technique and medium is even more important, as directional radio, satellite connections and for instance Googles Loon has to be handled differently in determining the real path length. In these cases the use of the road network might not be a reasonable solution for this task.

7. Conclusion

In this paper we propose an advanced model for IP Geolocation based on active measurements. We show the general usability of time measurements for high precision based on the selection and position of Landmarks. Our model is able to identify enhanced Landmark locations for probing. In addition, it compensates influences of real-world environments by a self-optimizing process. We have shown that the accuracy of the location determination does not increase with the amount of Landmarks used for probing, but the results are less vulnerable to measurement fluctuations. Considering other publication do not respect special cases like over-lapping circles during the process of lateration, our approach performs better. Also, the usage of road networks for distance estimation and respecting hop count leads to improved results, except for mentioned limitations. It localize more than 40% of the targets with a deviation less than 50 km. Currently we are evaluating our model in respect to moderated connected areas as well as intercontinental connections. We still have open issues in respect to model enhancements by possible overheads caused by IPv6 and further optimizations like analyzing the influence of the tracing algorithm on our model. Assigning every intersection point an individual probability may increase the identification of the dense cluster and therefore the target determination. Dynamic selected Landmarks, which are located near the estimated target, lead to improved measurement values.

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